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# PROBABILISTIC CONSEQUENCE ASSESSMENT OF HYDROGEN SULPHIDE RELEASES FROM A HEAVY WATER PLANT - SCOPE DETERMINATION

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**RESEARCH REPORT**

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# PROBABILISTIC CONSEQUENCE ASSESSMENT OF HYDROGEN SULPHIDE RELEASES FROM A HEAVY WATER PLANT - SCOPE DETERMINATION

## ABSTRACT

This report is concerned with the evaluation of the consequences to the public of an accidental release of hydrogen sulphide ($H_2S$) to the atmosphere following a pipe or pressure envelope failure, or some other process upset, at a heavy water plant. It covers the first stage of a programme in which the nature of the problem was analyzed and recommendations made for the implementation of a computer model.

The concepts of risk assessment and consequence assessment are discussed and a methodology proposed for combining the various elements of the problem into an overall consequence model. These elements are identified as the "Initiating Events", "Route to Receptor" and "Receptor Response" and each is studied in detail in the report. Such phenomena as the blowdown of $H_2S$ from a rupture, the initial gas cloud behaviour, atmospheric dispersion and the toxicity of $H_2S$ and sulphur dioxide ($SO_2$) are addressed. Critical factors are identified and modelling requirements specified, with special reference to the Bruce heavy water plant. Finally, an overall model is recommended for implementation at the next stage of the programme, together with detailed terms of reference for the remaining work.

## RÉSUMÉ

Ce rapport a pour but d'évaluer les conséquences pour le public d'un rejet accidentel d'hydrogène sulfuré ($H_2S$) dans l'atmosphère, à la suite de la rupture d'un tuyau ou du système de rétention sous pression, ou de telle autre perturbation du procédé, dans une usine d'eau lourde. Il traite de la première étape d'un programme qui analysait la nature du problème et qui recommandait la mise en application d'un modèle informatique.

Le rapport examine les concepts de l'évaluation des risques et de l'évaluation des conséquences, puis propose une méthodologie pour combiner les divers éléments du problème dans un modèle de conséquences global. Ces éléments s'appellent "Initiating Events" (conditions de déclenchement), "Route to Receptor" (acheminement vers le sujet exposé) et "Receptor Response" (réponse du sujet exposé), et chacun fait l'objet d'une étude détaillée. On présente notamment des phénomènes comme le rejet de $H_2S$ à partir d'une rupture, le comportement initial du nuage gazeux, la dispersion dans l'atmosphère et la toxicité du $H_2S$ et du bioxyde de soufre ($SO_2$). Le rapport identifie les facteurs critiques et spécifie les besoins en modélisation, en se référant particulièrement à l'usine d'eau lourde de Bruce. Enfin, pour la prochaine étape du programme, le rapport recommande la mise en application d'un modèle global, ainsi que l'établissement de directives précises pour le travail qui reste à terminer.

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## 1. Introduction

Heavy water (deuterium oxide) is an essential material in the Canadian nuclear industry, since it acts as both moderator and coolant in the present generation of CANDU reactors. Although heavy water occurs naturally in water bodies, the required quantities and purity for reactor use must be obtained by separating the heavy water from the light water with which it is diluted, normally in the ratio of about 5000 to 1. In Canada, this process is carried out in heavy water plants employing the Girdler-Sulphide method. There are three such plants currently in operation at Glace Bay and Port Hawkesbury, Nova Scotia, and Bruce County, Ontario. The plants are of considerable scale and complexity and, in general appearance and mode of operation, not unlike many other petro-chemical installations found across the country. In common with such installations, heavy water plants also require the use of toxic chemicals. In particular, the Girdler-Sulphide process employs large quantities of hydrogen sulphide ($H_2S$) which is recognized as a potential source of hazard to both the workforce and the general public in the vicinity of the plants. Although extensive precautions and contingency plans are in place to minimize the risk of exposure to injurious levels of $H_2S$, further study of this question is important to both operators and regulators as they seek to further reduce this risk.

This report is concerned with the evaluation of the consequences of an accidental release of $H_2S$ gas to the atmosphere following a pipe or pressure envelope failure, or some other process upset, at a heavy water plant. It is also concerned with the emissions of sulphur dioxide ($SO_2$) gas as a result of flaring of $H_2S$ from flare stacks, and with the emissions of $SO_2$ should an accidental release of $H_2S$ become ignited. The report covers the first stage of a programme in which the nature of the problem to be analyzed is studied and recommendations made for the implementation of a computer model. Once this model is operational, it will be possible to estimate the consequences of a postulated accident. Such consequences are best assessed in probabilisitc terms, given that the effects on the public would vary significantly according to initial gas behaviour, local weather conditions, population distribution around the plant, and the age and state of health of that population. For a given initiating event, i.e., size of pipe break or hole in a pressure vessel containing $H_2S$, and a defined set of weather and population conditions, the consequence, in terms of the number of casualties, would be calculated. Computer simulations of all such conditions, together with their associated probabilities of occurrence, will allow the generation of a probability distribution of consequences (number of casualties) corresponding to the postulated accident.

The results of the programme, once completed, are intended to assist the Atomic Energy Control Board (AECB) in the licensing of Canada's heavy water plants by significantly extending the present techniques of safety assessment applied to the plants. At present, licensees are required to report on the effects of possible process failures on members of the public. In the case of $H_2S$ releases to the atmosphere, this is normally done by calculating the downwind concentrations of the gas under a range of weather conditions, based on the $H_2S$ emission rate expected from a postulated pipe break. A number of pipe sizes are considered. The resulting gas concentrations are compared with a safe level for a 30 minute average exposure. The assessment of risk is then a judgement made by the AECB. The present programme will permit a quantitative assessment of risk assuming, of course, that the postulated accident occurs. This is termed a consequence assessment to distinguish it from a full risk assessment which requires that the probabilities of the initiating events also be included in the analysis. Some elements of judgement will therefore remain in the overall safety evaluation.

The purpose of the present stage of the programme outlined above is to identify the various conditions relevant to the problem, e.g., initial gas behaviour, atmospheric dispersion, population, toxicity of $H_2S$ and $SO_2$, and the preferred computer modelling tools to be used in the probabilistic consequence assessment. The detailed terms of reference are set out in Appendix A to this report and encompass a review of the nature of the initiating events, including the behaviour of the high pressure jet formed at the rupture, gravitational slumping of the resulting gas cloud, the possibility of $H_2S$ ignition, the behaviour of flares of burning $H_2S$, and plant aerodynamic wake effects. Study of the probability of occurrence of such events is specifically excluded. Also included is a review of atmospheric dispersion and the effects of $H_2S$ and $SO_2$ exposure, including topographic and climatological influences, available toxicity models, population data and meteorological data. The critical variables are to be identified, with their likely ranges of values, and the modelling requirements specified. These requirements, together with a review of available models describing the relevant conditions, then form the basis for recommending an overall model for implementation at the next stage of the programme. Finally, detailed terms of reference for the remainder of the programme are required.

It is intended that the end product of this work, the computer model, will be sufficiently general to be applied to all the heavy water plants in Canada. However, the resources available to the study at this stage, weighed against the importance of some site specific factors such as local topography and plant layout, dictated that a specific facility be selected as an example when reviewing the various factors in the consequence assessment. Ontario Hydro's plant in Bruce county, on the eastern shore of Lake Huron was selected by AECB staff for this purpose. The choice of Bruce HWP also implied that the influence of the gas dispersion systems installed around the Glace Bay and Port Hawkesbury plants would not be addressed. The gas dispersion systems, which are designed to detect a leak of $H_2S$ to the atmosphere and then artificially enhance the dispersion of the gas by means of large propane burners, require additional computer modelling components.

The report which follows begins with a brief discussion of certain concepts of risk assessment, and particularly the concept of consequence assessment invoked in this study and the methodology employed in combining the various elements of the problem into an overall consequence model. These elements are grouped under the headings of "Initiating Events", "Route to Receptor" and "Receptor Response" and are treated in Sections 3, 4 and 5 respectively.

In Section 3, the possible sources of $H_2S$ releases to the atmosphere are identified, starting from a brief description of the heavy water extraction process, the distribution of $H_2S$ inventories within the plant and the locations of pipework, process tower manways, storage tanks, flare stacks, etc., which represent the possible points of release. As discussed above, this has been done with specific reference to the Bruce HWP. The physical and thermodynamic properties of $H_2S$ are then reviewed, followed by the blowdown thermodynamics when either gaseous $H_2S$ or a gas and liquid mixture under pressure are expanded to atmospheric conditions through a break in the pressure envelope. The behaviour of the resulting jet is also discussed, together with the possibilities of autoignition of the gas, unconfined vapour cloud explosions (UVCE's) and impingement of the jet on the ground or plant structures. The flaring of $H_2S$ to $SO_2$ following an emergency or planned dump of $H_2S$ to the flare stack is addressed in this section. Section 3 ends with a summary of the possible initiating events to be modelled and the critical variables, e.g., the quantity of gas released, release duration, initial gas cloud density, effective release location and extent of the cloud.

Section 4 is concerned with the route to the receptor and begins with consideration of the initial gas behaviour, that is, the behaviour of flares, buoyant releases and, most significantly, heavier-than-air releases since, under some circumstances, it is concluded that $H_2S$ would be released as a cold, dense cloud. In this event, the initial slumping and ground-hugging characteristics of the cloud are important and have been investigated. Models to describe the initial gas behaviour are given. Section 4 also contains a review of the dispersion of the gases beyond the initial phase, where atmospheric turbulence is the dominant medium of dispersion.

The affects of meteorological parameters, such as wind, atmospheric stability, and mixing depth, as well as topographic and terrain influences, are discussed. Again, reference is made to the situation of the Bruce HWP, and especially the likely affect of the lake shore on dispersion in the area. Existing models available to simulate this phase of the route to the receptor are given, together with the meteorological data available to drive such models. Finally in Section 4, the routes to be modelled, the critical variables, e.g., initial gas behaviour, plume rise, time scales, meteorological variables, and the modelling requirements are summarized.

The third grouping of problem elements, "Receptor Response", is dealt with in Section 5. This begins with a short review of the toxic properties of both $H_2S$ and $SO_2$, available toxicity models and the significance of short-term concentration peaks which would occur in the gas cloud. With reference to the area around Bruce HWP, data on existing population are identified.

Section 6 contains a summary of the modelling recommendations and the detailed terms of reference for the remaining phases of the programme, i.e., model implementation and derivation of consequence probabilities.

## 2. Consequence Assessment Methodology

### 2.1 Risk Concepts

In general terms, risk can be defined as the probability of a certain outcome, usually unfavourable, occurring per unit number of people per unit time. For example, the risk of death in an automobile accident can be expressed in terms of the number of deaths per million of population per year. Of course, this is not the only way of expressing the same risk, for example, the total population can be replaced by the number of passenger miles, thus making the risk specific to those who travel in automobiles according to usage. However expressed, it is important to appreciate that risk is, of necessity, a statistical measure since the unfavourable outcome is a random event generally determined by a large number of factors, each with a certain probability of occurrence. Thus, the risk figure itself is subject to a certain degree of uncertainty, quantifiable as an 'error' or standard deviation.

In the above example relating to automobile accidents, the individual at risk is not identified. It is possible, on the other hand, to specify a hypothetical individual subject to a high level of risk from the same source, for example, a teenage driver with a record of speeding and drunk driving who never wears a seat belt. The risk to this individual can also be evaluated, but it would be distinct from the risk posed to the motoring public at large. These two types of risk have been called 'individual' and 'statistical' respectively, although a more appropriate name for the latter type might be 'collective', since both are statistical in nature. A further illustration, more related to the present study, concerns the release of a toxic gas to the atmosphere from a chemical plant. Usually, the person at the plant boundary is subjected to the greatest individual risk, particularly if elderly, infirm or in some way more sensitive to the toxic gas than the general population. However, this risk is not reflected in the statistical or collective risk, which would include the effects of population density, varied response to the gas from person to person and the decrease in concentration with downwind distance. It should be noted that a reduction in population density would reduce the collective risk, but not the individual risk posed to the person at the boundary. In general, the use of the collective risk is appropriate when assessing overall public safety in the event of a potential accident. Individual risk may be used as a basis for evaluating design changes, since such changes will have the greatest impact on persons identified as having a high individual risk (see also Whittaker, 1980).

In the present work, consistent with its ultimate application in public safety evaluation of heavy water plants, only collective or statistical risk is considered, i.e. incorporating the effect of population distribution and the variability of response to the toxic gases among that population.

## 2.2 Risk and Consequence Assessment

Risk analysis is a quantitative means by which the potential consequences or hazards of a given undertaking can be assessed. The end result, normally given as the probability of a certain unfavourable outcome, is determined by the following technique (Whittaker, 1980):

a) assemble an exhaustive list of the unfavourable outcomes

b) develop the chain of events leading to the outcomes

c) associate probabilities with the events

d) combine the event probabilities

In the case of an atmospheric release of $H_2S$ gas from a heavy water plant, we can identify one of the potential outcomes as deaths among the population downwind of the release. A simplified fault tree, which represents the chain of events culminating in this outcome is shown in Figure 1. With reference to the figure, we will identify the events leading up to and including a certain release of $H_2S$ as the initiating event and the deaths among the population as the consequences. The risk from the given initiating event is then given by:

$$\text{Risk from initiating event} = \text{Probability of initiating event} \times \text{Consequence of initiating event} \tag{1}$$

Now, as shown, the consequence will depend on the prevailing atmospheric conditions and the population encountered in the path of the release and so, to include all possible combinations of weather and population, we can write:

$$\text{Consequence of initiating event} = \sum_{p,w} \text{Consequence of initiating event when population } p \text{ exposed under weather condition } w \times \text{Probability of encountering population } p \times \text{Probability of weather condition } w \tag{2}$$

for all possible combinations of population density and weather (the probability of encountering p may be related to wind direction and other factors, such as time of day).

By substituting for the consequence of the initiating event from equation (2) in equation (1), and then repeating the exercise for all initiating events, i.e., all cases of the release of $H_2S$ to the atmosphere, the sum of the risks would represent the overall risk to the public from $H_2S$ releases from the plant (the above is similar to the formulation of risk from sour gas pipelines given by Andrews and Atwell, 1979).

## 2.3 Methodology for Current Work

As previously noted, the present study is restricted to probabilistic consequence assessment, given that a certain initiating event has occurred. Thus, it falls short of being a full risk assessment and is concerned only with the elements of equation (2).

Formalizing equation (2) in mathematical notation, the risk associated with a certain initiating event, or consequence, is given by:

$$R = \sum_{i,j,k\ldots} C_{i,j,k,\ldots} \times P_{i,j,k,\ldots} \qquad (3)$$

where $P_{i,j,k,\ldots}$ is the probability of weather conditions $i,j,k,\ldots$, e.g., wind direction, wind speed, atmospheric stability, which determine the relationship between the release and the gas concentration at the receptor. $C_{i,j,k,\ldots}$ is the consequence or number of fatalities under these same conditions. In this representation, $C_{i,j,k,\ldots}$ incorporates the effect of population density and the number of casualties per unit population exposed, integrated over the total area of influence of the release. The additional population probability term in equation (2) is omitted since, at any given location, population exposed is assumed to be most strongly correlated with weather conditions, primarily wind direction. In equation (3), the value R is the expectation of the number of casualties arising from the initiating event.

In a further refinement of the description of consequence which will be used in this report, the number of fatalities is itself expressed in probabilistic terms. The consequence is given by the equation:

$$P(R_n) = \sum_{i,j,k,\ldots} P(C_{i,j,k,\ldots} = n) \times P_{i,j,k\ldots} \qquad (4)$$

where $P(C_{i,j,k,\ldots} = n)$ is the probability of n casualties under weather conditions i,j,k,... and $P\,(R_n)$ is the probability that the consequence is n casualties. This important modification allows an assessment to be made of the variability of the consequence. As well, it allows the inclusion of a probabilistic toxicity model, incorporating variable response to the gas among the exposed population and the so-called peak-to-mean effect due to short term concentration fluctuations (Monserco,1981)

In summary, the methodology of consequence assessment to be followed in this work is given by Figure 1 and equation (4). A number of initiating events will be postulated, but probabilities will not be attached to these. An initiating event will be taken to mean a given release of $H_2S$, $SO_2$ or some mixture of gases, specified as to quantity of release, duration of release, extent of the initial cloud, physical state and effective point of release. The route to the receptor is then primarily weather and terrain dependent and results in a certain pattern of gas concentrations downwind. The number of casualties, or receptor response, is determined as a probability distribution.

## 3. Initiating Events

### 3.1 Potential Sources of Release

### 3.1.1 Process Description

At Canadian heavy water plants the extraction of heavy water is carried out by the Girdler-Sulphide process. The initial stage of extraction is performed in Enriching Units, which provide a product stream containing 99.75 mol percent of deuterium to the Finishing Units. The latter units then further concentrate the product to the required purity. Hydrogen sulphide is used in the Enriching Units, each unit having an $H_2S$ inventory of some 540 tonnes*.

The Enriching Unit utilizes the property of deuterium atoms to concentrate in water at low temperatures and in hydrogen sulphide gas at high temperatures. There are three stages per unit, each having a hot and cold section. Deuterium enriched $H_2S$ is transferred between the hot sections of the first, second and third stages, carrying with it increasing concentrations of deuterium. Finally, in the third stage, water in the cold section tower contains sufficient heavy water to be removed for final processing in the Finishing Unit. Figure 2 shows the flow of gas and water between the various stages of the enriching process. It should be noted that there are three first stage towers operated in parallel. The third stage hot and cold sections are in separate towers, while the second stage consists of a single tower.

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*Process information is based on Part I (Design Description), Bruce HWP Safety Report, Ontario Hydro, 1978.

The transfer of deuterium atoms between the water and $H_2S$ streams is accomplished by forcing the gas up through perforated trays containing a shallow stream of water. This is also depicted in Figure 2. The operating temperatures of the cold and hot sections are 32°C and 128°C respectively, and the system operating pressure is approximately 2080 kPa. The major equipment associated with the Enriching Units are the pumps and blowers, which maintain the flow of liquid and gas, and heat exchangers which recover heat when liquid flows from hot to cold sections. This equipment is located at ground level immediately adjacent to the towers.

Considering the example of the Bruce HWP, there are two plants currently in operation (Bruce HWP's A and B), each comprised of two units. A further two units (Bruce HWP D) are partially complete, but construction on this plant has been suspended.

### 3.1.2 Hydrogen Sulphide Inventories

As noted above, the normal $H_2S$ inventory of an Enriching Unit at Bruce HWP is about 540 tonnes, distributed between three stages (six towers). This inventory includes $H_2S$ in gaseous form and some in solution with water. A representative distribution of the inventory of a first stage tower is given in Table 1. It shows that more than 90% of the $H_2S$ occurs as gas, with somewhat more than half of this in the cold, upper section of the tower. This distribution is believed to be approximately true of the Enriching Units as a whole.

$H_2S$ is also contained in the piping and equipment of the Enriching Unit. The major $H_2S$ carrying pipes are identified below. All carry $H_2S$ in gaseous form under pressure:

| | |
|---|---|
| 3 x 1.3m (52 in) | lines carrying cold $H_2S$ from top to bottom of the first stage towers |
| 3 x 1.1m (42 in) | lines carrying cold $H_2S$ from the top of the second stage tower to the centre of each first stage tower |
| 3 x 1.1m (42 in) | lines carrying hot $H_2S$ from the centre of each first stage tower to the bottom of the second stage tower |
| 1 x 0.6m (24 in) | line carrying $H_2S$ from the top of the hot third stage tower to the bottom of the cold third stage tower |
| 1 x 0.6m (24 in) | line carrying $H_2S$ from the top of the cold third stage tower to the centre of the second stage tower |
| 1 x 0.6m (24 in) | line carrying hot $H_2S$ from the centre of the second stage tower to the bottom of the hot third stage tower |

The above piping, together with associated equipment, smaller interconnecting pipes and liquid lines, etc., are estimated to account for about 20% of the total $H_2S$ inventory of the Enriching Unit (ref. Port Hawkesbury HWP Safety Analysis).

The $H_2S$ storage area of a heavy water plant normally contains a significant inventory, stored under pressure in liquid form at saturation conditions (2720 kPa and 38°C). At Bruce HWP there are six 'bullet' tanks, each having a capacity of 180 tonnes of $H_2S$. In an adjacent area rail tank cars of liquid $H_2S$ are parked and unloaded. The maximum capacity of cars currently in use is 46 tonnes.

At the plant's $H_2S$ recovery area, gas is stripped from depleted process water and waste streams and returned to the process. At Bruce HWP, the recovery unit consists of two stripping towers, although the largest contribution to the $H_2S$ inventory in this area is a compressor suction tank having a capacity of 100 tonnes.

The transfer of $H_2S$ between the Enriching Units, Storage and Unloading Area, Recovery Area and flare stacks (used to burn $H_2S$ which may be dumped in the event of a process upset) is primarily through a system of 0.05, 0.1, 0.15 and 0.3m lines (2, 4, 6 and 12 inch). These are suspended on pipe racks which, at Bruce HWP appear to be between 6 and 10 m above ground level. Line pressure is normally 2350 kPa, with the exception of the return line from the recovery area which operates at 500 kPa. The pipes extend over considerable distances within the plant, as shown in the layout diagram of the Bruce HWP given in Figure 3. Although a definitive figure for the $H_2S$ inventory contained within these lines does not appear to be available, it has been estimated at 0.7 tonnes for the Bruce plant, based on double lines of average diameter 0.1m following the dotted lines shown in the figure.

Table 2 summarizes the $H_2S$ inventory for the Bruce HWP, as discussed above. Both the A and B plants are assumed to be operating at full capacity and the existing storage tanks are assumed full. A single tank car is included in the storage area inventory.

### 3.1.3 Possible Points of Release

It is the purpose of the following section of this report to identify potential points of release of either $H_2S$ or $SO_2$ in order that modelling requirements can be specified. Therefore, a broad view of possible initiating events has been taken without any attempt to assess the credibility or likelihood of these events. In this way, the model should be capable of dealing with the full range of cases which, at some later date, may be considered worthy of detailed consequence assessment.

Failure of the $H_2S$ containment systems in the Enriching Units, storage and unloading area, $H_2S$ recovery area and interconnecting pipes is of primary concern. Possible causes of such an event have been identified as follows (Glace Bay HWP, Safety Assessment, Jan 1973):

- failure of blower seals
- failure of flanges on smaller gas lines and tower manholes
- valve stem leakage
- failure of rotary machinery
- pressure vessel and piping failure
- earthquake, wind and ice loading
- aircraft strike
- loss of process feedwater, cooling water, steam or electrical power
- failure of tracing system and formation of hydrate ($H_2S.6H_2O$) plugs damaging pipework
- failure of propane supply to flare
- human and operational errors
- general component deficiencies
- fires and explosions

Although various design features and operating procedures are in place at heavy water plants to minimize the likelihood of such events, nonetheless it is possible that an $H_2S$ release could be precipitated at any point in the containment system. Scenarios range from a catastrophic failure of an Enriching Unit tower or storage tank down to a minor leak at a valve stem or flange.

In the case of the Bruce HWP, the extent of $H_2S$ containment and the inventories associated with the major elements of the system have been identified in Section 3.1.2. From Fig. 3, it is apparent that a release could occur from any point within a wide area inside the plant. Elevations of release could range from, effectively, ground level to the flare stack tip (145m), depending on which part of the process is affected.

The Enriching Unit towers and some pipework rise to about 110m above grade (108m for Bruce A and 114m for Bruce B), although most $H_2S$ carrying lines and equipment are found close to ground level, approximately within the first 10m. The larger lines (0.6-1.3 m, or 24-52 inch diameter) carrying $H_2S$ between different stages of the enriching process extend alongside the towers, in some cases along the full height and, in other cases, only half the height (see Section 3.1.2). In addition, manholes are located in the walls of the process towers to provide access during maintenance. These are 0.6m (24 in) in diameter and at various levels depending on the process stage. Figure 4 gives a diagrammatic representation of one of the two enriching units at Bruce HWP 'A'. Manhole locations are shown on the diagram. As indicated, there are up to seven manholes per tower at elevations ranging from 7.7 to 80.8 m above grade. At Bruce, all manholes are on the north sides of the towers.

In the $H_2S$ storage and unloading area, tanks and pipes are generally at or near ground level. At Bruce HWP, the 'bullet' storage tanks are arranged in a row, each one oriented in an east-west direction with a mass of pipework, mainly of small diameter, extending along the east side of the row. Tank-car unloading takes place at the north end of this area. Pipework in this area is estimated to be mostly 3-5m above grade, and may carry $H_2S$ in either liquid or vapour form. The area is dyked to contain spills of liquid $H_2S$ should this occur. Short of a catastrophic failure of a storage tank or tank car, the largest potential release in this area would be due to the failure of a tank manhole. These are normally of 0.6m (24 in) diameter and located on the top of each tank, approximately 4m above grade.

The two flare stacks at Bruce HWP are shown on Figure 3. The more southerly stack serves plant A only, while the other stack can serve either plant A or B (or D when operational). Both stacks are 145m high. An emergency dump of $H_2S$ to the flare stack would normally be ignited at the stack tip by the propane system and burn to $SO_2$. However, failure of the ignition system would result in the release of pure $H_2S$ from the stack.

As previously noted, interconnecting pipework in a heavy water plant is carried on piperacks. At Bruce HWP, pipe elevations on these racks are about 8 to 10m above grade. Finally, potential gas releases in the $H_2S$ recovery area would take place near ground level. The largest inventory in this area is in the compressor suction tank, located at grade, although the stripper towers themselves extend to some 21m above grade and must be considered a potential accidental source of $H_2S$.

### 3.1.4 Release Scenarios

Licencees of heavy water plants in Canada have concentrated, in their safety assessments, on certain $H_2S$ release scenarios which are considered to be the worst credible. With the exception of the failure of a 0.6m (24 in.) manhole, catastrophic failures of the pressure envelope have not been addressed. As well, the larger pipe breaks are believed to autoignite to $SO_2$ and, thereafter, represent a reduced safety hazard to the public (see, for example, Bruce Heavy Water Plant Safety Report Section II.3 (Gas Release Calculations), 1980 and 1982 (draft)). Table 3 summarizes the scenarios considered to date for the Bruce HWP, together with the assumed location of the release and the gas release rate. It is believed that similar conditions have been examined at Glace Bay, as well as the consequences of burning $SO_2$ releases for 0.05 through 0.6 m diameter breaks. A release for a stripper tower was also considered, assumed to take place 'at the top of a process tower'.

Although the above situations may be illustrative of credible initiating events, they do not cover the full range of possible cases. Table 4 has been assembled on the basis of what is conceivable without, admittedly, the benefit of an examination of the likelihood of the situations ever arising. As previously stated, such an examination is beyond the scope of the present study. The expanded list of scenarios presented in the table is intended solely to permit the specification of a modelling procedure which could, if required, handle the full range of cases. Not all specific cases of possible equipment failure have been included (e.g. stripper tower failure) Those excluded are believed to be of lesser severity and, because of similarities to other scenarios, would not expand the modelling requirements.

## 3.2 Nature of Releases

### 3.2.1 Physical-Chemical Thermodynamic Properties of $H_2S$

The physical, chemical and thermodynamic properties of $H_2S$ are of particular relevance to the initial flow of gas or liquid through a postulated rupture in the pressure envelope and the immediate disposition of the resulting release. Therefore, these properties are briefly reviewed below.

$H_2S$ is a colourless, flammable and highly toxic gas with a characteristic odour of rotten eggs. The principal physical-chemical properties are summarized in Table 5. In addition to these, the phase properties of $H_2S$ are often required in thermodynamic calculations. The projection of the normal pressure-volume-temperature (p-v-t) surface on the p-v plane is illustrated in Figure 5 together with some of the relevant parameters for $H_2S$. In the context of the Girdler-Sulphide process, it is noteworthy that, in the high pressure environment of the process, $H_2S$ in solution with water can pass from a liquid phase into a solid hydrate phase, which effectively sets lower limits on operating temperatures and pressures. Further data on $H_2S$-$H_2O$ physical properties are given by Neuburg et al (1977).

### 3.2.2 Classification of $H_2S$ Releases

For the purposes of describing the initial behaviour of the release, the scenarios listed in Table 4 can be conveniently classified according to the physical state of the $H_2S$ within that part of the containment affected and the size of the rupture. These are:

a) Hole in vapour space
(enriching unit towers, gas lines, small hole in vapour space of storage tank)

b) Large hole in liquid storage tank

c) Small hole in liquid space (small hole in liquid space of storage tank or liquid line)

In the case of an emergency dump to flare, it is assumed that the flow of $H_2S$ will be governed by flow through the dump valve in a manner similar to a) above.

a) Hole in Vapour Space

In this situation, pure vapour would be released through the hole at sonic velocities. The process would be similar to the classical thermodynamic problem of choked flow through a convergent nozzle from a reservoir, where the ratio of the external ($p_e$) and internal ($p_i$) pressures is less than the critical pressure ratio for the gas, i.e.

$$\frac{p_e}{p_i} < \left(\frac{p_b}{p_i}\right)_{crit} \qquad (5)$$

where $p_b$ is the pressure at the break and

$$\left(\frac{p_b}{p_i}\right)_{crit} = \left(\frac{2}{n+1}\right)^{\frac{n}{n-1}} \qquad (6)$$

n is the index of the polytropic expansion relation $pv^n$ = constant ($n = \gamma$ = ratio of specific heats for a perfect gas)

For hydrogen sulphide gas, $n \simeq 1.3$, so that

$$\frac{p_b}{p_{i\ crit}} = 0.54 \qquad (7)$$

Thus, it can be seen that, where the reservoir or pipe pressure is greater than about 200 kPa, choked flow occurs and sonic velocities exist at the hole. This is important in limiting the initial release rate and is the most significant flow regime when considering possible $H_2S$ releases, since typically 90% of the release will occur under these conditions. Once subcritical flow is established, the release rate and subsequent downwind concentrations are very much reduced.

It is usual to assume isentropic flow during discharge, i.e. ideal or frictionless flow with no heat transfer. Then, the mass discharge rate is given by (e.g. Vennard, 1961, Rogers and Mayhew, 1957):

$$Q = A_b \sqrt{\frac{\gamma p_i}{v_i} \left( \frac{2}{\gamma+1} \right)^{\left[ \frac{\gamma+1}{\gamma-1} \right]}} \qquad (8)$$

where $A_b$ is the area of the hole and $v_i$ is the gas specific volume inside the reservoir. The discharge coefficient for the nozzle implied in isentropic theory is 1.0, however, in practice the vena contracta effect and the effect of friction at sharp-edged breaks, cracks and valves etc. produce an effective coefficient less than 1.0. As well, in the case of discharge from an enriching unit process tower, flow would likely be further restricted by water trays and baffles and, in the case of a pipe break, by frictional resistance. Values of the coefficient have been suggested for cracks, safety valves and round openings of 0.2, 0.6 and 0.8 respectively (BHWP Safety Report, II.3). In the case of the failure of a 0.6m (24 in) manhole, a coefficient between 0.5 and 0.6 has been suggested elsewhere.

A phenomenon associated with the rapid expansion of vapours is the formation of supercooled vapour in so-called metastable states. This would occur at the low pressures found near the break in the pressure envelope and would result in increased flow through the opening. Restoration of thermodynamic equilibrium occurs irreversibly with an increase in entropy and pressure after the exit. In practice, it is unclear to what extent the thermal inertia of the equipment will offset this effect, thus reducing the flow rate to be closer to the ideal flow case suggested by equation (8) above. Data generated by AECL for the flow of a real gas, suggest that without accounting for thermal inertia, the initial flow rate from a failed manhole would be about 1650 kg/s, compared with 1100 kg/s for ideal flow (from Enriching Unit second stage cold tower at 32°C and 2200kPa). Nevertheless, for practical purposes, it is felt that equation (8), with use of a suitable discharge coefficient to account for the irreversibilities discussed above, is suitable for determination of gas flow rates in the present context. The choice of discharge coefficient should be the subject of further investigation and sensitivity analysis.

Under choked flow conditions, the time history of the discharge is controlled by the reservoir or pipe pressure, $p_i$. The time history of $p_i$ has been shown to be governed by the equation (e.g. Allen, 1976)

$$p_i = p_{o_i} e^{-kt} \qquad (9)$$

where $p_{o_i}$ is the initial reservoir pressure and k is a constant which depends on the reservoir volume, the size of the break and the reservoir temperature. For $H_2S$, Allen gives an equation for k as follows:

$$k = \frac{\alpha\ 2.72 \times 10^3\ A_b}{\sqrt{T_i}\quad \bar{v}} \qquad (s^{-1}) \qquad (10)$$

where $T_i$ is the reservoir temperature, $\bar{v}$ the effective volume, $A_b$ the break area and $\alpha$ is an empirical factor to allow for friction. Allen presents values of $\alpha$ determined from experimental data collected at Glace Bay HWP, where blowdowns through emergency dump values were measured. Values ranged from 0.26 (0.05m or 2 in dia) to 0.64 (0.15 m or 6 in dia).

To establish the orders of magnitude of the release rates and the characteristic time constants of the blowdown curves, several of the scenarios given in Table 4 have been evaluated using the above equations. It is assumed that a single first stage tower of volume 5000m³ (including associated piping and equipment) is discharged through the break. The average tower temperature is taken at 353K (hot and cold sections), and the initial system pressure 2090 kPa. The time constant evaluated is the time required to reduce the pressure in the tower to the critical pressure (~ 200 kPa), at which point choked flow no longer exists at the break. Results are given in Table 6. In this evaluation, no credit is given for operator action. This may have the result of reducing the quantity of gas released and the release duration.

In the event of a discharge from an isolated length of pipe, the contents of a sufficiently long pipe would discharge in thermal equilibrium with its surroundings. The resulting isothermal flow problem has been discussed by Wilson (1979) with application to sour gas pipe lines. The process can be described by a double-exponential blowdown curve (Bell, 1978), although the first exponential term applies only to the first few seconds as a pressure wave migrates down the pipe from the break to an isolation valve. Thereafter, its release rate follows an exponential curve similar to equation (9). In a heavy water plant, it is believed that the initial transient effect would be very small, so that equations (8) and (9) would provide a good approximation to the discharge history from an isolated pipe.

Considering again choked flow at a hole in the vapour space, for a perfect gas it can be shown that the temperature $T_b$ at the break is given by

$$\frac{T_b}{T_i} = \frac{2}{\gamma + 1} \qquad (11)$$

where $T_i$ is the reservoir temperature. Thus, for $H_2S$

$$\frac{T_b}{T_i} \equiv 0.87 \qquad (12)$$

The velocity at exit is the local sound speed

$$C_b = (\gamma R T_b)^{\frac{1}{2}} \qquad (13)$$

Thereafter, the gas expands irreversibily to atmospheric pressure through a series of shock waves with a concomitant increase in both entropy and temperature. Thus, in the example of $H_2S$ expanding from an initial reservoir temperature of 32°C (cold tower of enriching unit) the gas temperature cannot drop below -7.7°C and, in fact, would rapidly reach atmospheric conditions after the shock and subsequent jet.

The jet of $H_2S$ emerges initially at the sound speed, i.e. approximately 290 m/s. Ambient air is rapidly entrained in a manner which can be predicted by invoking conservation of momentum and mixing length theory (see Schlichting, 1968). The velocity falls in direct proportion to distance from the break, while the width increases correspondingly, i.e.

$$u_{max} = \text{const. } \frac{1}{x} \sqrt{\frac{J}{\rho}} \qquad (14)$$

$$b = \text{const. } x \qquad (15)$$

where $u_{max}$ is the centreline velocity, J the momentum, $\rho$ the density and b the width of the jet. Experimentally the constant is found to be of the order of 0.2, i.e. the jet half angle is approximately 5-6°. Thus, for a 0.6m (24 in) diameter break, the centreline velocity falls to one tenth of its initial value at a distance of some 27m from the break, and to one hundredth of the value 300m from the break, at which points the jet width is 6 and 60m respectively. Considering a break in a 50 mm (2 in) diameter pipe, the corresponding distances are 2.3 and 25m and the jet widths 0.5 and 5m. Experimental evidence suggests that the jets can be considered to be dissipated well before 100 break diameters.

During a catastrophic failure of an Enriching Unit process tower, there exists the possibility that process water will become entrained with the gas release. Based on consideration of the area of the water trays, this is felt to be unlikely for all but the largest breaks. Nevertheless, should this occur, it is worthwhile to consider the effects on the $H_2S$ discharge to the atmosphere.

The typical breakdown of the inventory of a first stage tower given in Table 1 suggests that the quantity of gas released could be increased by up to 10%, that is, by the amount of $H_2S$ in solution in the process water. Assuming, for Bruce HWP, a first stage water inventory of 500 $m^3$ and an $H_2S$ inventory of 120 tonnes, it is expected that approximately 12 tonnes of this inventory will be present in solution. However, this corresponds to about half of the solubility of $H_2S$ in water at atmospheric conditions, leading to the conclusion that, upon releases, the dissolved gas would effectively remain in solution over the period of the postulated accident.

b) Large Hole in Liquid Storage Tank

There are now a number of well documented accounts in the literature of the behaviour of vapour clouds resulting from catastrophic failures of storage tanks in which the vapour is initially stored under pressure as a liquid. This experience has been summarized by Kaiser and Griffiths (1980) with particular reference to ammonia (see also Kaiser and Walker, 1978). Upon rupture of the container the pressure above the liquid surface is relieved instantaneously and pressures at and below the surface of the liquid are below the saturated vapour pressure. Boiling of the liquid then occurs to the extent that the heat capacity of the liquid can provide the necessary heat of vapourization. In the case of $H_2S$ stored at saturated conditions, this is equivalent to 42% of the storage tank inventory. The remaining liquid remains at the boiling point of -60.7°C. Where the size of the rupture is of the same order as the liquid surface area, this liquid becomes airborne as a cloud of fine droplets. This has been confirmed in recent experiments by ICI in Great Britain (see also Maurer et al, 1977).

Ambient air is rapidly entrained to evaporate these droplets, resulting in significant cooling of the air and gas mixture and the formation of a dense, heavier than air cloud. This has been observed, even in the case of ammonia, which is lighter than air at standard conditions.

Haddock and Williams (1978) present a method to determine the density of the resulting cloud when a pure vapour and droplet combination is mixed with dry or wet ambient air. For the present purposes, we will consider only mixing with dry air. By equating enthalpies before and after mixing, it can be shown that the final equilibrium temperature, T and density $\rho$ of the $H_2S$ and air cloud are given by

$$T = \frac{75.57 + 67.98\ R}{0.243 + 0.249\ R} \qquad (16)$$

$$\rho = \frac{542.3\ (1 + R)}{(1.54R + 1.2)T} \qquad (17)$$

where R is the air/$H_2S$ mass ratio.

It was assumed that the initial temperature of the vapour is 38°C. (Saturation temperature in the storage tank) and the ambient temperature 0°C. Under these same conditions, the final temperature and density of the cloud resulting from a release of vapour and droplets, following complete evaporation of the droplets, is given by:

$$T = \frac{67.98R + 75.57 - 131.5F}{0.249R + 0.243} \qquad (18)$$

$$\rho = \frac{1 + R}{[2.833R + 2.379]\ T \times 10^{-3}} \qquad (19)$$

where F is the fraction of the total mass of $H_2S$ initially in the liquid phase.

A difficulty arises in the determination of the value of R in the above equations, i.e. the amount of ambient air entrained at the time of release. Unfortunately, for catastrophic failures, as opposed to well behaved jets, there appears to be little guidance provided by the literature in this area, although Hardee and Lee (1975) have presented a method for predicting the initial growth of the gas cloud from the rupture of pressurized liquid containers. This three-stage model begins by assuming isentropic flow of two phase fluid through the rupture to obtain momentum flow rate as a function of time. The second stage involves increase of the cloud height to a final value equal to the cloud radius at the end of this stage. This stage occurs relatively rapidly. Thereafter, the cloud radius expands according to some function of time. The final cloud size, and hence volume of air entrained, can be expressed in terms of the initial mass of liquid, area of the rupture and initial temperature. The solution of the problem for the specific case of liquid $H_2s$ requires a numerical solution of the two-phase flow problem, which was not attempted at this stage of the present study. However, the necessary relationships can be developed for $H_2S$ and it is recommended that this be done in a subsequent phase of the work.

By way of illustration it will be noted that Hardee and Lee present data which allow the prediction of final cloud size for the rupture of a tank of $SO_2$. If we assume an inventory of approximately 100 tonnes with catastrophic failure of the end cap of a 'bullet' tank (approximate area 7 m²) initially at a temperature of 300K, at the end of a minute, or ten times the tank dump duration of 6 seconds, the cloud is approximately 73m high and 160 m in radius, with a volume of approximately $2 \times 10^6 m^3$. In the case of a similar release of $H_2S$, the cloud size can be expected to be of the same order as the corresponding $SO_2$ cloud, so that the value of R would be approximately 70. Applying this figure in equations (18) and (19), the cloud temperature and density would be about -7°C and 1.33 kg/m³ (c.f. density of dry air at 0°C, 1.29 kg/m³). This would represent the situation close to the final expansion of the cloud.

It should be noted, however, that earlier in the cloud history the density of the mixture would be higher, although still expanding under the influence of the initial momentum of the decompression. For example, at 30 seconds, the air/gas mass ratio is 44 and the temperature and density of the equivalent $H_2S$ air mixture -11°C and 1.35 kg/m³ respectively.

### c) Small hole in Liquid Space

This case has been discussed by Kaiser and Walker (1978). If a hole occurs in the liquid space of the vessel or a liquid line, it is though that the jet will consist initially of unflashed liquid. Upon expansion to atmospheric pressure the liquid will flash to vapour, causing rapid expansion of the jet with a half angle which can exceed 90°. This is a consequence of the entrainment of air required to vaporize the liquid. Where the jet emerges from a length of pipe exceeding a certain length there exists the possibility that flashing will occur within the pipe itself, resulting in a two-phase jet at the break. The critical length to diameter ratio for steam is about 10, but is unknown for $H_2S$. This phenomenon would effectively reduce the discharge rate, but an estimate could be made by assuming unflashed liquid at the break followed by flashing to vapour in the resulting jet. The flow rate of liquid is derived simply from Bernoulli's equation:

$$Q = \rho A_b \sqrt{2 \frac{p}{\rho g}} \qquad (20)$$

where $\rho$ is the fluid density (900 kg/m³ for saturated liquid $H_2S$), p the tank pressure and g the acceleration due to gravity.

Thus, the discharge through a 0.05m (2 in dia) liquid line from a storage tank of saturated liquid $H_2S$ would be somewhat less than 137 Kg/s, depending on the assumed discharge coefficent. The jet emerges at approximately 80 m/s and, unless this impinges on the ground or other structure (see below), would rapidly vapourize as violent mixing occurs in the jet. The heat of vapourization is obtained from the liquid itself and the ambient air.

### 3.2.3 Release Involving Burning or Explosion of $H_2S$

It is known that $H_2S$ is a flammable gas with an ignition temperature of 260°C and upper and lower fammability limits in air of 44 and 4% respectively (see Table 5). When $H_2S$ burns, the flare temperature, allowing for heat loss due to radiation, excess air entrainment and dissociation, has been estimated at 980°C. The heat of combustion is 15,300 kJ/kg (Glace Bay HWP Safety Assessment, Jan 1973).

In the heavy water plants gaseous $H_2S$ is contained in carbon steel vessels which would normally develop an interior coating of pyrophoric ferrous sulphide according to

$$Fe + H_2S \rightarrow FeS + H_2$$

In the event of a break in a vessel, it has been the position of heavy water plant licensees that, for all but the smallest breaks, small particles of ferrous sulphide would be blown through the hole and spontaneously ignite, as:

$2\ FeS + 3O_2 \rightarrow 2\ FeO + 2SO_2 + 5370$ kJ/kg FeS.

This would result in immediate ignition of the $H_2S$ and burning to $SO_2$ as follows.

$2\ H_2S + 3O_2 \rightarrow 2SO_2 + 2H_2O + 15{,}300$ kJ/kg$H_2S$

1.9 kg of $SO_2$ is formed from combustion of 1 kg of $H_2S$. Thus, in the view of the licensees, this would preclude the formation of potentially explosive concentrations of $H_2S$. It is understood that this position is based on experience at existing heavy water plants, although it is not clear under what conditions this occurred. In view of the apparent paucity of data relating to this phenomenon, it is not possible at this stage to conclude whether or not ignition would occur under specific postulated break conditions. Therefore, it will be assumed for the purposes of specifying modelling requirements that both situations should be analyzed, the principal differences between the two being in the nature and quantity of gas released and the heat of combustion, which would be available to enhance subsequent dispersion of $SO_2$. In addition, there will be some differences between jets of burning and pure $H_2S$, primarily reflected in a larger jet half angle.

Should unignited $H_2S$ be released to atmosphere, it is clear that the subsequent $H_2S$/air mixture will pass through the explosive concentration range of the gas (44-4%) and thus represent an explosion hazard. It is for this reason that attention has been focussed on the possibility of a spark or flame igniting the cloud and precipitating a so-called unconfined vapour cloud explosion (UVCE). This phenomenon has recently been subjected to an exhaustive review by Gugen (1978) and the reader is referred to this reference for further information. However, some of the conclusions of Gugen's study are quoted here to provide some context for the assessment of possible UVCE's at heavy water plants:

a) Based on a review of accidents since 1921, statistics show that few major chemical, petrochemical, process or petroleum plants have escaped the possibility or actually of an UVCE. Trends in frequency, proportion of incidents involving blasts, fatalities in UVCE's are all upwards.

b) No flammable material can be excluded as a potential 'fuel' for an UVCE, if a large escape of the material could mix rapidly with air.

c) Blast efficiency related to TNT cannot be predicted with any confidence from a knowledge of the flammable material and quantity escaping to the atmosphere.

d) It would appear to be necessary that most vapours capable of causing a UVCE be denser than air at both the point of release and in the explosible mixture with air. (This would be true of $H_2S$ in, for example, the case of failure of a liquid $H_2S$ storage tank - see above).

e) An elementary theory for the prediction of pressure effects resulting from UVCE's is presented. The theory suggest that pressure waves would be of sufficiently long duration to be manifested as static loads on most structures.

It should be noted that in none of the 100 cases cited by Gugen was $H_2S$ involved, although many of the circumstances involved the kind of plant systems, storage or transportation vessels encountered in heavy water plants.

### 3.2.4 $H_2S$ Jet Impingement on Ground or Plant Structures

A secondary effect which must be considered, since it may influence the nature of the release of $H_2S$ to the atmosphere, is the impingement of the initial release on the ground or some part of the plant structure. An appreciation of the order of magnitude of the size of the initial jet or cloud can be gained by reference to Section 3.2.2 above. In a complex of piping and equipment it is clear that the likelihood of physical interference with the initial release is high, except where discharge occurs from a manhole high on a process tower. The possible consequences of this interference are:

a) fragmentation of the jet, thus increasing the effective volume of the resulting air/gas cloud.

b) a secondary rupture of the pressure envelope due to the force exerted by the jet or cloud.

c) where the jet consists of flashed vapour, some proportion of the release may be recovered as liquid which will then collect in a pool in the area and revapourize slowly as heat is drawn from the surroundings.

This phenomenon has been noted in ammonia jets by Resplandy (1969), but there appears to be no reliable method of quantifying this effect.

### 3.3 Modelling Requirements

In the preceding sections we have discussed certain classes of initiating events and concluded the predominant physical factors which determine the nature of the gas release in each case, methods for predicting the quantity and time history of the discharge, and the relevant physical characteristics of the initial gas cloud. The specific parameters which are of interest as input to the prediction of cloud transport and dispersion, and hence to the consequence assessment, are:

- gas emissions ($H_2S$ or $SO_2$)
- duration of release
- location
- physical extent of cloud
- cloud density

Table 7 summarizes the characteristics of the release scenarios previously identified; according to the above listed parameters. Where specific models are recommended for evaluation of these parameters, the appropriate equation number in the text, or reference, is given.

# 4. Route to Receptor

## 4.1 Initial Gas Behaviour

The previous section of this report demonstrated that there are a number of possible release mechanisms of $H_2S$ or $SO_2$ to the atmosphere, depending on the initiating event which is postulated. These mechanisms will affect the subsequent atmospheric dispersion of the gas and the concentrations received at ground level downwind. For the purposes of modelling the initial gas behaviour, the following classifications can be made.

- neutrally buoyant release of a $H_2S$/air mixture
- burning jets and flares
- heavier-than-air release of a $H_2S$/air mixture

### 4.1.1 Neutrally Buoyant Release

In many cases of neutrally buoyant or passive releases, $H_2S$ is initially diluted with air in a vigorous jet which forms at the break location. Where this jet is vertical, or has a significant vertical component, the effective elevation of the release will be influenced by the local wind speed, producing a bent-over plume of gas. This situation can be adequately represented by equations recommended by Briggs (1969 and 1975) based on conservation of momentum. The momentum rise is given by

$$\Delta h = 3 \frac{wo}{u} D \qquad (wo/u \geq 4) \qquad (24)$$

for rise in neutral, windy conditions,

$$\Delta h = 4 \left(\frac{Fm}{s}\right)^{\frac{1}{4}} \qquad (25)$$

in windless conditions, and

$$\Delta h = 1.5 \left(\frac{Fm}{u}\right)^{1/3} s^{-1/6} \qquad (26)$$

under stable atmospheric conditions with some wind. However, Briggs recommends that, because of limited experimental evidence to support these equations, the last equation (26) be used where this predicts a lower plume rise. In the above equations, $w_0$ is the initial jet velocity, u the wind speed, D the initial jet diameter and Fm the buoyancy flux. s is a stability parameter defined by

$$s = \frac{g}{T} \frac{\partial\theta}{dz} \qquad (27)$$

where T is the ambient temperature and $\frac{\partial\theta}{\partial z}$ the potential temperature gradient in the atmosphere. In view of the fact that final momentum rise is achieved within a few jet diameters downwind, it should be unnecessary to include the plume trajectory equation in this application. The release of gas may then be thought of as emanating from a point corresponding to the physical release height plus the momentum rise, with an initial radius obtained from the jet equation, i.e., equation ( 15). However, it may be further subjected to plant wake effects as discussed later in this section.

### 4.1.2 Burning Jets and Flares

When a jet of $H_2S$ autoignites or is dumped to the flare stack and ignited, the initial behaviour is predominantly controlled by buoyancy generated from the heat of combustion. Again, Briggs has recommended equations to predict buoyant plume rise based on an extensive review of various formulae and experimental data (Briggs, 1970 and 1975). The plume rise as a function of downwind distance is given by:

$$\Delta h = 1.6\ F^{1/3}\ u^{-1}\ x^{2/3};\quad x < 3.5\ x^* \qquad (28)$$

$$\Delta h = 1.6\ F^{1/3}\ u^{-1}\ (3.5x^*)^{2/3};\ x > 3.5x^* \qquad (29)$$

where x* is a characteristic distance, as

$$x^* = 14F^{5/8}\quad ;\quad F \leq 55m^4/s^3 \qquad (30)$$

$$x^* = 34F^{2/5}\quad ;\quad F > 55m^4/S^3 \qquad (31)$$

F is the buoyancy flux.

Equations (28) and (29) above apply to neutrally stratified atmospheres and satisfactorily to unstable ones. It is recommended that they also be used for slightly stable atmospheres if the resulting rise is lower than that predicted by the following:

$$\Delta h = 1.6\ F^{1/3}\ u^{-1}\ x^{2/3}\quad ;\quad x \leq 2\ us^{-\frac{1}{2}} \qquad (32)$$

$$\Delta h = 2.9\ \left(\frac{F}{us}\right)^{1/3}\quad ;\quad x > 2\ us^{-\frac{1}{2}} \qquad (33)$$

In very light winds, however, the following best applies

$$\Delta h = 5.0\ F^{\frac{1}{4}}\ s^{-3/8} \qquad (34)$$

It is important to note that the expressions for plume rise normally found in the literature, including those quoted above, are intended for application to emissions of hot gases from chimney stacks. The present application differs from this in two important respects; firstly, there is an unconfined burning jet or flare formed at the break or flare stack tip and, secondly, the release may occur close to ground level.

Relatively little is known about flare behaviour as it affects plume rise. However, this question has recently been studied by Alberta Environment (1980). They recommend use of the normal equations, such as those given above, with the following definition of the buoyancy flux term:

$$F = 0.000037\ Q_h \qquad (35)$$

where $Q_h$ is the dry heat emission in calories per second, calculated using the low (net) heat values for the flare fuel. This is 22.2 MJ/m³ for $H_2S$ (at 15.6°C and 101.3 kPa). A further 25% is deducted from the net heat value to allow for radiation losses.

In general, the heat generated by burning jets of $H_2S$ would produce a very high plume rise and hence small concentrations of $SO_2$ downwind. For example, the release caused by the rupture of a 0.15m (6 in) gas line would generate an initial $H_2S$ flow rate of some 84 kg/s and, when completed combusted, 158 kg/s of $SO_2$. The calculated plume rise is initially 1700 m and ground level $SO_2$ concentrations close to zero (neutral stability, wind speed 5m/s). When the flow rate has fallen to a tenth of its initial value, the plume rise drops to about 430 m. In the latter case recordable levels of $SO_2$ are predicted at ground level, with a maximum of approximately 870 μg/m³.

This suggest that particular attention be given to $SO_2$ emissions towards the end of the blowdown time history when plume rise is decreasing at a much greater rate than the emission rate.

Although the release is buoyant, this does not necessarily mean that it will rise if it is initially in contact with the ground. It has been suggested (Briggs, 1973), that whether or not lift-off of the plume occurs depends on the relationship between the self-generated turbulence in the plume and atmospheric turbulence. Lift-off is suppressed if the following parameter is less than a certain critical value:

$$\frac{g\ z\ (\rho_a - \rho_o)}{u_*^2\ \rho_a} \tag{36}$$

where z is the height of the cloud, of density $\rho_o$, $\rho_a$ is the density of the ambient air and $u_*$ is the turbulent friction velocity. The critical value of the parameter appears to be of the order of 10. The friction velocity can be calculated from the wind speed using the equation:

$$u = \frac{u_*}{k}\ \ln\left(\frac{z}{z_o}\right) \tag{37}$$

where u is the wind speed at height z and $z_o$ is the roughness length (about 1/10 the typical height of the roughness elements on the ground, such as buildings, trees, grass etc.) k is von Karman's constant, usually taken as 0.4.

### 4.1.3 Heavier-than-air Release

Where the resulting gas cloud is heavier than air, as in the catastrophic failure of a liquid $H_2S$ storage tank, there are a number of important phenomena which have been observed and should be included in any dispersion model. Following the formation of the dense mixture itself, treated in Section 3.2.2 of this report, the resulting configuration of the cloud can be idealized as a cylinder which then undergoes (see Reid, 1980 , Kaiser and Walker, 1978, Edisvik, 1980):

a) gravitational slumping, during which there is relatively little entrainment of ambient air and the cloud simply flattens out.

b) ground hugging, during which the cloud entrains air and its height begins to grow, but at a rate slower than would be the case for a passive cloud.

c) transition to a passive plume, which takes over when density effects become small. The cloud then behaves as a normal passive release, but with a larger initial width and smaller initial height.

a) Gravitational slumping

In the initial stage the cloud slumps in the same manner as a column of liquid and the radius of the cylinder increases as follows:

$$\frac{dr}{dt} = c \left[\frac{\rho - \rho_a}{\rho} gh\right]^{\frac{1}{2}} \qquad (38)$$

wherein $\rho$ is the gas density, $\rho_a$ the ambient air density and h the cloud height. c is a constant, usually taken to be 1.0, based on the experimental results of Van Ulden (1974). By holding the volume (v) and density constant in the liquid column analogy, i.e.

$$v = \pi r^2 h \qquad (39)$$

it can be shown that the radius at time t is given by

$$r^2 = r_o^2 + 2c \left[\left(\frac{\rho - \rho_a}{\pi \rho}\right) gv \right]^{\frac{1}{2}} . t \qquad (40)$$

where $r_o$ is the initial radius. The assumption of negligible ambient air entrainment, as well as the form of equation (40) are substantially supported by experimental work reported by Britter (1979). According to Van Ulden, the end of the slumping phase is determined by comparison of the buoyancy induced velocities with turbulent velocities, i.e., where the parameter

$$\frac{(\rho \quad \rho_a)gh}{\rho\, u_*} \qquad (41)$$

falls below a certain critical value ($u_*$ is the friction velocity from equation (37) above). Van Ulden suggests a critical value of 4, although it is pointed out by Fryer and Kaiser (1979) that this can lead to unrealistically low cloud heights at the end of the slumping phase. They suggest that slumping is assumed to have terminated when the height h is comparable to the height of surface roughness elements.

b) Ground hugging

In the three stage model, entrainment of ambient air first takes place during ground-hugging although, in more complex models, this also occurs in the slumping phase.

Entrainment into the cloud at its edges is similar to a passive cloud, but entrainment at the top surface is inhibited by the stable density gradient near the cloud top. A number of mathematical description of this vertical entrainment have been presented in the recent literature, e.g., Zeman (1982), Cox and Roe (1977), but this appears still to be a very uncertain area.

The general equation for the rate of entrainment of ambient air is

$$\frac{dm_a}{dt} = \underbrace{\rho_a\,(\pi r^2)\,u_e}_{\text{vertical entrainment}} + \underbrace{2\,\rho_a\,\pi r h\,\alpha^*\,\frac{dr}{dt}}_{\text{horizontal entrainment}} \qquad (42)$$

where $\alpha^*$ is an empirical constant, the value of which is uncertain, based on experimental evidence (Fryer and Kaiser, 1979). $u_e$ is the vertical entrainment velocity dependent on shear at the cloud top. The form of the equation for $u_e$ varies. For example, in Zeman's approach, it has the form:

$$u_e = \frac{\alpha_1}{\alpha_2 + R_i} v_T \qquad (43)$$

where $\alpha_1$, $\alpha_2$ are constants, $v_T$ is the characteristic turbulent velocity and $R_i$ is the Richardson number. Following Cox and Roe,

$$u_e = \frac{\alpha_3 v_T}{R_i} \qquad (44)$$

The Richardson number is defined by:

$$Ri = \frac{g \; l \; (\rho - \rho_a)}{v_T^2 \; \rho_a} \qquad (45)$$

where l is a length scale as a function of height above ground.

### c) Transition to Passive Plume

A number of different criteria have been applied in the literature to account for this transition. An obvious approach is to compare the cloud density in the ground-hugging phase, allowing for the progressive entrainment of ambient air, with the ambient air density. Where the difference is small, say, 0.1%, the gas is thereafter assumed to behave as a passive release. An alternative approach compares the rate of growth of a passive cloud with the rate of growth of the dense cloud, given by equation (38) above. From Gifford (1976), for atmospheric turbulence dominated growth:

$$\frac{dr}{dt} = C \, \bar{u} \qquad (46)$$

where $\bar{u}$ is the mean wind speed transporting the cloud.

Thus, the criterion for transition reduces to

$$\sqrt{\frac{\rho - \rho_a}{g \, h \, \rho_a}} < \text{const } \bar{u} \qquad (47)$$

wherein the constant depends on atmospheric stability.

Now, if the transition occurs at a point $x_t$ downwind of the source, at which point the height and radius of the cloud are $h_t$ and $r_t$ respectively, then the Gaussian standard deviations describing the spread of the cloud at a point x downwind of the original release point can be represented by:

$$\sigma_y^2 (x) = \left( \frac{r_t}{2.14} \right)^2 + \sigma_y \, (x-x_t) \qquad (48)$$

$$\sigma_z^2 (x) = \left( \frac{h_t}{2.14} \right)^2 + \sigma_z \, (x-x_t) \qquad (49)$$

This makes the normal assumption that the edge of the cloud at transition corresponds to the 10 percentile level of the Gaussian concentration curve.

The above discussion has neglected the influence of heat transfer from the ground during the gravitational behaviour of the cloud. Clearly, where there is a temperature difference between the cloud and the ground, this may result in enhanced dispersion of the gas. Kaiser and Walker (1978) have presented formulae for estimating the sensible heat transfer for laminar and turbulent convection (see also any good fluid dynamics text with a section on convective heat transfer, e.g. Olson, 1966). In general, turbulent heat transfer predominates in the atmospheric environment, so that the heat transfer rate per unit area is given by:

$$Q_c = a\ (\Delta T_g)^{4/3} \qquad (50)$$

where $\Delta T_g$ is the temperature difference between the ground and the cloud and a is a constant depending on the cloud properties (coefficient of expansion, viscosity, thermal conductivity, specific heat and typical dimension). The rate of increase of temperature of the cloud is then represented by:

$$\frac{dT}{dt} = \frac{a\ (\pi\ r^2)\ \Delta T_g^{\ 4/3} + \frac{dm_a}{dt}\ C_{p_a}\ \Delta T_a}{m_a\ C_{p_a} + m_g\ C_{p_g}} \qquad (51)$$

where m is the mass and $C_p$ the specific heat at constant pressure of the air (a) and the gas (g). According to Kaiser and Walker, the effect of forced convection is negligible in this context and, provided the gas in question is transparent to solar radiation, this source of heating can also be neglected. (The second term in the numerator of the above equation represents the heating effect due to entrainment of ambient air, where $\Delta T_a$ is the temperature difference between the environment and the cloud).

Allowing for both entrainment and convective heating, the problem is then represented by equations (38, 42, and 51), which must be solved numerically.

A useful illustration of the significance of gravitational slumping and ground hugging on the dispersion of $H_2S$ can be obtained by considering the example of a release of

100 tonnes of liquid $H_2S$ introduced in Section 3.2.2. Consider the initial $H_2S$/air mixture of density 1.33 kg/m³ and temperature -7°C. The approximate cloud dimensions are 73m high by 160m radius (volume $2 \times 10^6$ m³). By ignoring entrainment and cloud heating the following result is obtained from equation (40):

$$r^2 = 2.6 \times 10^4 + 80t \qquad (52)$$

We now apply Fryer and Kaiser's criterion for termination of the slumping phase and set the critical cloud height at 1m, on the order of the height of roughness elements near the plant boundary. The corresponding cloud radius at this point is 800m and occurs after 10 seconds of slumping. The cloud then grows in the vertical at a rate determined by shear-induced entrainment at the top of the cloud until it approaches the rate of growth of a passive cloud. The typical time history of both the vertical and horizontal spread of the cloud is represented in Figure 6.

### 4.1.4 Plant Wake Effects

The general aerodynamic effect of an obstacle, such as a plant building or structure, is illustrated in Figure 7. The flow is characterized by a region of recirculating flow, or cavity, in the lee of the building, a turbulent wake extending downwind and accelerated displacement flow immediately above the obstacle. Releases made close to the obstacle, in either the upwind or downwind direction, may be subject to entrainment in the wake or cavity region with the following results: relatively high concentrations at ground level near the obstacle and enhanced mixing such that concentrations further downwind are lower than would be the case without the obstacle.

In any given situation the flow conditions and dispersion effects would be highly site-specific and depend on such factors as the dimensions of the subject structure, as well as other structures in the immediate vicinity, wind speed and direction, local topography and ground surface roughness. Usually, physical modelling in a wind tunnel is recommended to precisely evaluate the effects. However, some guidelines are available in the literature for prediction purposes. In particular, Lucas (1962) provides a relationship which can be used to determine the ratio of the effective height of release of the gas plume to the height of the interfering obstacle, as shown in Figure 8. The effective plume height is intended to account for enhanced dispersion in the wake, as well as downward displacement of the plume centreline. However, where cavity entrainment occurs (release height ≤ 1.6 obstacle heights) the additional dispersion can be represented by adding a term to the normal dispersion coefficients ($\sigma_y$, $\sigma_z$), i.e.

$$\sigma_y'^2 = \sigma_y^2 + \frac{CA_o}{\pi} \qquad (53)$$

$$\sigma_z'^2 = \sigma_z^2 + \frac{CA_o}{\pi} \qquad (54)$$

where $A_o$ is the area of the obstacle presented to the incident wind vector and C is a constant dependent on obstacle shape and porosity.

At a heavy water plant, the most significant aerodynamic obstacle is formed by the complex of equipment and pipework alongside the enriching unit towers, as well as the towers themselves. However due to the complexity of this and adjacent structures, and in the absence of a wind tunnel study, it is difficult to establish reliable estimates of the effects on dispersion. An order-of-magnitude estimate could be obtained, however, by considering an idealized rectangular structure of the same width and area as presented by the enriching unit complex and taking the value of C in the above equations as 1.0 (see Halitsky, 1968).

It is important to qualify the above discussion, in that it applies to passive releases or, at least, releases which do not possess significant positive or negative buoyancy. The interaction of building wake and buoyancy is complex, and, as far as we are aware, practical mathematical models are not available to represent the situation. Indeed there is little experimental evidence on which to base any model, although we are aware that work is underway in this area at the Warren Springs Laboratory in the U.K. (Kaiser and Griffiths, 1980).

## 4.2 Gas Transport and Dispersion in the Atmosphere

In the following section of this report we will be concerned with the transport and diffusion of the gas release following the initial buoyancy and/or momentum dominated phase, i.e., the release is assumed to be passive at this stage, although the effective-point of release and initial dimensions of the cloud are important to the determination of downwind concentrations in the passive stage.

In general, the speed and direction of transport is determined by the average wind conditions and the diffusion is determined by atmospheric turbulence or "gustiness". Turbulence in the atmosphere is usually related to atmospheric stability. Broadly speaking unstable conditions enhance dispersion and stable conditions inhibit dispersion.

The factors which determine wind and stability conditions at a given time and place are numerous and, in some cases, interrelated in a complex fashion which is not fully understood by atmospheric scientists. However, they can be summarized as follows:

First, the large-scale or synoptic weather conditions determine the general wind direction and speed, as well as the overall thermodynamic state or stability of the atmosphere. Locally, this will be modified by radiative heating and cooling of the earth's surface. Thus, such factors as cloudiness, surface albedo, time of day and time of year enter the picture. Other local factors of potential significance are terrain roughness, proximity to a large city, and topographic features such as a lake or ocean shoreline, mountains and escarpments. One phenomenon of particular importance to gas dispersion, and resulting from certain synoptic or local conditions, is a so-called temperature inversion or stable layer aloft, trapping the release in a relatively thin layer next to the ground.

Some important distinctions must also be made concerning the nature of the source of the gaseous release. The release can be classified as continuous, or effectively continuous if the duration of release is equal to or greater than the mean travel time from source to the point of interest. In this case, diffusion in the alongwind direction can be disregarded. The plume of gases is in a steady state with concentration a function of position relative to the source alone. Alternatively, in the case of a short-term release, as from a catastrophic pressive envelope failure, the gases are emitted as a cloud or puff. The puff then follows a path determined by the average wind conditions, and concentration within the puff is determined by alongwind diffusion, as well as lateral and vertical diffusion about the puff centroid. The concentration observed in the path of the puff is a function of both time and position.

As previously mentioned, other important characteristics of the source are its effective elevation and initial dimensions.

Fundamentally, there are three theoretical bases for dispersion modelling. These are:

(a) Models based on the statistical theory of turbulence. A central assumption in this theory is that the form of the distribution of diffusing particles is normal, or Gaussian.

(b) Models based on so-called gradient transfer theory, involving solution of the differential equations of diffusion.

(c) Models based on similarity theory, in which the dependence of concentration on position within the diffusing plume or cloud is derived from dimensional analysis.

A major difficulty in the application of gradient transfer theory to practical dispersion problems is determination of the coefficients of the equations (the eddy diffusivity coefficients). These are not easily measured, and there is little basis in the literature for assuming specific values in a given situation. Moreover, solution of the equations, except in the simplest cases, requires numerical methods and considerable computational effect. On the other hand, similarity theory yields less information about the spatial distribution of concentrations than either statistical (Gaussian) or gradient transfer theory. Thus, Gifford (1975) has concluded that:

> "the Gaussian formula, properly used, is peerless as a practical diffusion modeling tool. It is mathematically simple and flexible (and) it is in accord with much though not all working diffusion theory".

Gaussian models have gained wide acceptance by regulatory bodies concerned with environmental protection and public safety.

As stated above, dispersion of the gases can be in the form of a plume or puff, depending on the duration of the release. As well, the release may be at ground level or elevated and, if it has some initial dimension, can be considered as being emitted from an area source or a virtual point some distance upwind of its real location.

### 4.2.1 The Gaussian Plume Model

The distribution of the gases within a continuous plume is assumed normal or Gaussian in both the vertical and lateral directions, as shown in Figure 9 . The equation for finding the concentration at any point in the plume is given in the figure. For concentrations at ground level on the centreline of the plume, the equation simplifies to:

$$X(x,o,o;H) = \frac{Q}{2\pi\sigma_y\sigma_z u} \exp\left\{-\tfrac{1}{2}\left(\frac{H}{\sigma_z}\right)^2\right\} \qquad (57)$$

When the source is at ground level:

$$X(x,o,o;o) = \frac{Q}{\pi\sigma_y\sigma_z u} \qquad (58)$$

Modifications of the equations are available for such situations as an inversion aloft (see Turner, 1970).

The dispersion coefficients are normally given as functions of downwind distance and atmospheric stability, and have been derived from experimental observations. They describe the spread of material at a given point, averaged over a period of 10 minutes to one hour. (see Section 4.2.3 below).

It must be emphasized that the Gaussian plume model does not apply in stagnation or near stagnation conditions. As well, it rests on a number of important assumptions, i.e.

- continuous emission from the source over a period greater than or equal to the mean travel time between source and point of interest.
- chemically stable pollutants which are completely reflected at the ground and inversions aloft.
- no change of atmospheric stability through the mixing layer and no turbulent transfer through layers of dissimilar stability.
- no variation of wind speed and direction with height.
- an averaging time of 10 minutes to one hour, depending on the dispersion coefficients used.
- steady, uniform meteorological conditions throughout the dispersion field.

### 4.2.2 The Gaussian Puff Model

The distribution of gases within a puff is assumed normal or Gaussian in three dimensions. Figure 10 shows the idealized puff and the general equation for determining concentration. At a point at ground level on the centreline of the cloud's path, the concentration is given by:

$$X(x,o,o,t;H) = \frac{2Q_T}{(2\pi)^{3/2}\sigma_x\sigma_y\sigma_z} \exp\{-\tfrac{1}{2}(\frac{x-ut}{\sigma_x})^2\} \qquad (61)$$

$$\times \exp\{-\tfrac{1}{2}(\frac{H}{\sigma_z})^2\}$$

For a ground level source:

$$X(x,o,o,t;o) = \frac{2Q_T}{(2\pi)^{3/2}\sigma_x\sigma_y\sigma_z} \exp\{-\tfrac{1}{2}(\frac{x-ut}{\sigma_x})^2\} \qquad (62)$$

As the puff passes over the point of interest, the gas concentration rises to a peak and then falls off. The exponential term in the last equation gives concentration at a point x at time t. The peak concentration experienced at x is, therefore:

$$X(x,o,o,o;o) = \frac{2Q_T}{(2\pi)^{3/2}\sigma_x\sigma_y\sigma_z} \qquad (63)$$

In this case, the dispersion coefficients express the instantaneous distribution of material about the centroid of the puff as it moves downwind. The expansion of puffs in the atmosphere has not been studied to the same extent as continuous plumes. Consequently, there is little experimental evidence on which to base values of the coefficients. (see 4.2.3).

Many of the assumptions underlying the plume model and listed above also apply to the puff model (except those concerning duration of release and averaging time).

### 4.2.3 Dispersion Coefficients

Incomplete knowledge of the Gaussian dispersion coefficents ($\sigma$'s) is a major difficulty when applying the plume, and especially puff, equations. Several versions of the $\sigma$ functions are to be found in the literature, perhaps the most commonly used being from Turner (1979) and ASME (1973) for the continuous plume model. The selection of appropriate functions depends on such factors as the release height, terrain conditions and atmospheric stability. The classification of atmospheric stability for this purpose is, in itself, an area of considerable debate.

In 1977 a workshop, convened by the American Meteorological Society and including some of the most experienced workers in this field, recommended that, wherever possible, the horizontal plume sigma, $\sigma_y$ be determined from the standard deviation of wind direction, $\sigma_\theta$, as measured by a sensitive wind vane at the site in question. The form of the relationship is:

$$\sigma_y = \sigma_\theta \times f\ (x) \tag{64}$$

Pasquill (1976), in a recent review of available sigma data, concluded that an appropriate function, f(x), is as follows:

| x (km) | 0.1 | 0.2 | 0.4 | 1 | 2 | 10 | 10 | >10 | |
|---|---|---|---|---|---|---|---|---|---|
| f(x) | 0.8 | 0.7 | 0.65 | 0.6 | 0.5 | 0.4 | 0.33 | 0.33 | $(10/x)^{\frac{1}{2}}$ |

Where measurements of $\sigma_\theta$ are not available, the workshop recommended that other estimates can be obtained from:

(a) existing $\sigma_y$ curves, but adjusted for sampling time and terrain roughness.

(b) climatological values of $\sigma_\theta$, to be developed from available measurements of $\sigma_\theta$ in terms of insolation, wind speed and terrain roughness.

(c) climatological values of $\sigma_\theta$ derived from similarily theory in terms of mixing height and a characteristic stability length scale.

When considering vertical dispersion ($\sigma_z$), a simple formula is suggested, valid for small downwind distances, an elevated source and where $\sigma_z$ is less than the source height, viz:

$$\sigma_z = \sigma_\phi x \qquad (65)$$

where $\sigma_\phi$ is the standard deviation of the wind elevation angle. Otherwise, literature values may be used but represent only "a very unfinished state of the art".

In summary, a review of the literature on plume dispersion coefficients suggested that the following sigma values be adopted for the present purposes:

(a) where climatological $\sigma_y$ and $\sigma_z$ values can be developed from available measurements of $\sigma_\theta$ and $\sigma_\phi$, these should be used, categorized according to height above ground, atmospheric stability as measured by a stability length scale or non-dimensional parameter (e.g. Richardson Number), upstream terrain roughness and inversion height (if atmosphere highly unstable).

(b) where direct measurements of wind direction variations are not available, literature values be used from Briggs (1973), where the effective release height is greater than 100m, or Hosker (1974)*, for release heights less than 100m. The latter set of functions take into account roughness length in the determination of $\sigma_z$. In both cases the well known Pasquill stability class (A-F) must be specified (see, for example, Turner, 1970).

As previously noted, there is little guidance available in the literature for an appropriate choice of puff sigma functions. Some limited $\sigma_y$ and $\sigma_z$ functions we presented in Slade (1968), and these are widely used. Even less information is available on $\sigma_x$, but this can usually be taken to be equivalent to $\sigma_y$. In any case, Slade's functions are applicable only to a range of 100m to 4km downwind.

More recently, Doury (1972) presented puff sigma values as functions of travel time. These have been compared with Slade's in numerical experiments (Daggupaty, 1980) and it was concluded that Doury's functions fare better under low wind speed conditions, producing more realistic and less conservative results. Nevertheless, it must be emphasized that the experimental evidence for either approach is scant and lacking in sufficient generality to provide reliable results at any given location. It is therefore recommended that, in the present study, plume sigma values be applied to short-term or puff releases and the momentarily high concentrations which would be experienced in the direct path of a puff be simulated by the statistical peak-to-mean model for plumes (Monserco, 1981).

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*As recommended in draft CSA Standard N288.2, July 1981.

### 4.2.4 Chemical Decay of $H_2S$

Recently, the chemical decay of $H_2S$ was reviewed as part of the National Research Council's report on scientific criteria for environmental quality (NRCC, 1981). Reaction rates, k, for Canadian latitudes were estimated to be approximately $5.2 \times 10^{-8}\ s^{-1}$ in January and $9.4 \times 10^{-7} s^{-1}$ in July. The effect can be represented in the normal Gaussian dispersion euqations by a decay term which reduces the ground level concentration as:

$$e^{-kt} \qquad (66)$$

There is also a corresponding build-up of $SO_2$ as a result of the reaction. However, in this application where travel times to receptors are relatively short, these factors are not considered significant.

### 4.2.5 Dispersion Model Accuracy and Sensitivity

The accuracy of a model prediction of gas concentration depends on two fundamental factors. First, one must consider how well the model represents the actual physics at work in the atmosphere. Such simplifying assumptions as total reflection of the gas at the ground and at inversions aloft, uniformity of meteorological conditions and the Gaussian assumption itself are all possible sources of error. Given good quality input data, Gaussian models should be accurate to within about 20% when used to simulate long term (seasonal or annual average) concentrations, or to within a factor of 2 to 3 when used for short-term episodes.

However, inaccuracies in meteorological and source input data can lead to much larger errors in the results. The potential magnitude of these errors can be assessed by considering model sensitivity to changes in input parameters, as follows.

Consider a continuous ground level release of a gas and the decrease of ground level concentration with distance along the plume centre-line according to the Gaussian model. Values of the concentration factor XU/Q have been plotted in Figure 11 for six stability categories, ranging from A (most unstable), through D (neutral) to F (most stable). When the concentration, X, release rate, Q, and wind speed, U, are combined in this way the results for each stability category collapse onto a single curve.

These curves, and the basic equations given earlier, show that the concentration at any point is directly proportional to release rate and inversely proportional to wind speed. Thus a given error in either of these quantities will result in an equivalent error in the concentration. The curves in Figure 11 also show how concentration is sensitive to downwind distance, rougly as a power law function. Thus, when presented as a log-log plot, the curves approximate straight lines. In the case of the neutral (category D) curve, for example, there is a 50-fold dilution between 100m and 1 km and a 30-fold dilution between 1 km and 10 km.

Again referring to Figure 11, it can be seen that an error of one stability category (or equivalent in terms of the dispersion co-efficients used), will give an error in concentration of between a factor of 2 and 10 at distances between 1 km and 10 km. Conversely, such an error in stability category would result in a 1.5 to 4-fold error in estimated downwind distance required to achieve a certain level of concentration. This potential error increases with distance from the source.

Figure 12 gives the corresponding curves of concentration factor versus distance from the puff model. The dispersion coefficients used were those suggested in Slade (1968) for unstable neutral and stable atmospheres.

In this case, sensitivity to downwind distance and stability is generally greater than for the plume model (it should be noted that wind speed appears as a factor only in the determination of stability category).

Other potentially significant sources of error not illustrated in the figures include wind direction and the effective height of the release. For Gaussian plumes and puffs, it can be shown that maximum ground level concentration is approximately proportional to the inverse square of the release height. Thus a 50% inaccuracy in the prediction of, for example, the rise of a hot plume, will give a 115% error in predicted maximum ground level concentration.

The correct determination of wind direction is often most critical, particularly when stable atmospheric conditions prevail. Considering the plume model under category F conditions, the lateral dispersion coefficient at 1 km is about 33m, corresponding to the horizontal standard deviation of the concentration profile. Under the Gaussian model, concentration falls to 10% of the maximum centre-line value in 2.15 standard deviations, or 71m in this example. Thus, an order of magnitude error in predicted concentration can result from just a 4° error in wind direction. Of course, such potential errors can be ignored in applications where wind direction is immaterial.

In the context of the present application to consequence assessment, which considers the full range of possible dispersion conditions and uses long term climatological data as input, many of the potential errors will tend to be self concelling. However, where a particular situation gives rise to a relatively large number of casualties, inaccuries in the prediction of the critical episode can be expected to have a major influence on the final result.

## 4.3 Site-Specific Factors - Bruce HWP

The Bruce heavy water plant is situated on the eastern shore of Lake Huron between the communities of Kincardine and Port Elgin in Bruce County (see map, Figure 13 ). The terrain is gently rolling in this part of Ontario and major land use in the area is farming. The most significant topographic feature, from the point of view of dispersion of airborne emissions, is the lakeshore which, at this location, is orientated in a SW-NE direction. Thus, winds roughly from the SW through NW to NE approach the site over water. Effective terrain roughness lengths ($z_o$) over water should be of the order of 0.1 cm, whereas over land this increases to about 5 cm. (Davenport, 1966). As well, under conditions in which stable air flows off the lake and there the land surface is warmer than the lake, a thermal internal boundary layer (TIBL) may be established. This is manifested as an inversion, overlaying comparatively unstable layer, which progressively increases in height with distance inland. Releases which occur above the inversion may be fumigated to ground level further inland, while dispersion of releases directly into the TIBL may be restricted in the vertical by the presence of the inversion. An excellent account of shoreline dispersion phenomena has been given by Lyons

(1975), who presents a 3-stage model for fumigation in the TIBL based on Turner's (1970) procedure for inversion breakup fumigation of a Guassian plume. It is suggested that this procedure be used for safety analysis at the Bruce site, together with the usual trapping formulation for released within the TIBL (see Turner, 1970). However, an outstanding requirement, which must be met before this model can be implemented, is a suitable climatological description of the TIBL, i.e. inversion height versus inland distance and stability of the internal boundary layer.

While terrain in the Bruce area is generally gently rolling to the east of the heavy water plant site, there is a small escarpment of bluffs about 30m (100 ft) high which runs in a SW-NE direction.The closest approach of the bluffs to the site is approximately 3.5 km. to the ESE. Such an abrupt increase in elevation can be expected to adversely affect ground level concentrations as an elevated cloud of gas passes over the bluffs. The effect would be most significant in stable flows, although the small elevation involved and the distance from the plant would suggest only a minor increase in concentrations. Nevertheless, it is recommended that a simple representation of elevated terrain be included in the dispersion model in order to study the sensitivity to this effect (e.g. Burt, 1977).

Climatological data from the area of the Bruce HWP have been summarized by Wong (1973). For the purposes of dispersion analysis, the critical variables can be identified as the wind speed, wind direction, atmospheric stability and mixing height. The latter parameter indicates the restriction on vertical mixing. Wong presents monthly average wind speeds by direction and wind direction frequencies at Wiarton (1955-66) and Southampton (1959-66). A limited amount of data is also provided from Douglas Point and Bruce, all observations being made at the reference level for surface winds of 10m (33 ft). Frequency distributions of Pasquill stability categories are given by month and wind direction for Wiarton (1962-71). This is the closest first-order meteorological station providing the necessary observations on a 24 hour basis needed to determine surface stability frequencies, although a second station is located at Goderich, about 64 km (40 miles) to the south. Wiarton is some 56 km (35 miles) northeast of the Bruce site and Southampton about 24 km (15 miles) northeast. An updated wind speed/direction/stability frequency analysis for Wiarton and Goderich is obtainable from AES. Unfortunately, mixing heights for this particular part of Ontario are not readily available, since historical data of this kind are only collected and analyzed at routinely operated upper air stations. The closest such station is at Flint, Michigan. In addition, gross seasonal measurements of mixing height, e.g. mean afternoon mixing height, can be read from climatological maps of Canada (Portelli, 1977).

Some site specific data are available to calibrate such historical data to the area of the Bruce plant. A 100 m meteorological tower at the shoreline at the south end of the site is instrumented at three levels as follows:

| PARAMETER | ELEVATION |
|---|---|
| Wind speed (u) | 100, 30, 10 m. |
| Wind direction ($\theta$) | 100, 30, 10 m. |
| Temperature | 10m |
| Differential temperature | 100-10m, 50-10m |
| $\sigma_\theta$ | 100m |

The wind direction signal from the uppermost level is fed to an MRI sigma meter which provides a continuous readout of $\sigma_\theta$. It is understood that records are now maintained on magnetic tape, as well as on strip charts. Data collected since September 1980 is believed to be relatively good*.

A methodology for adjusting historical wind and stability data collected at one site to be representative of another site has been applied elsewhere by Baynes (1981). Only a limited period of record is necessary at the subject location and this appears to be available at Bruce, i.e. winds at 10-100 m and vertical temperature profile, which is an alternative measure of atmospheric stability, over a one year period. It is recommended that this be done for Bruce before the final consequence assessments are carried out. The work would make use of existing data only and would not require further field measurements to be taken.

## 4.4 Modelling Requirements

This section of the report has been concerned with the initial behaviour of a release of $H_2S$ or $SO_2$ to the atmosphere and the subsequent transport and dispersion of the gas. Specific equations and models have been discussed and recommended, and these are summarized in Table 8 according to the different phenomena to be simulated, the required input and output data. Appropriate equation numbers in the text, or references, are given. In addition, two specific recommendations are made for the development of the dispersion climatology of the Bruce site which will be required before final consequence assessments are carried out. These are:

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*Data between September 1980 and February 1981 were abstracted by Monserco Limited in the course of an earlier study for Environment Canada.

(a) determination of representative thermal internal boundary layers (TIBL) arising from the lake breeze,

(b) derivation of site specific wind and stability frequency distributions using historical data from Wiarton and/or Goderich and on-site meteorological tower data collected since 1980.

## 5. Receptor Response

### 5.1 Toxicity of $H_2S$

The effects on man of $H_2S$ at various concentrations in air are summarized in Table 9 . The toxicity of $H_2S$ was investigated in an earlier report by Monserco Limited (1981) for the Atomic Energy Control Board and the reader is referred to that report for further details. The literature on both animal studies and cases of human exposure was cited to determine a lethal dose relationship (concentration-exposure time) for exposures of one or two breaths up to about one hour. Short-term lethal threshold concentrations were proposed as follows:

- 860 ppm (1200 mg/m³) for 0-0.5 minutes, representing the "instantaneous" mode of action, thought by some to be due to direct paralysis of the respiratory centre.
- 500 ppm (700 mg/m³) for 0.5-10 minutes, representing acute systemic poisoning.
- 290 ppm (400 mg/m³) for 10-60 minutes, representing sub-acute poisoning.

The step-function form of the lethal dose relationship is illustrated in Figure 14.

The threshold for central nervous system (CNS) depression, possibly leading to unconsciousness and death by secondary causes, was set at 180 ppm (250 mg/m³).

These levels were designed to be reasonably conservative and to represent minimum dose levels since, in any accident situation, it was recognized that persons of different ages and widely different states of health would potentially be involved. As well, many might be in a state of stress and increased physical activity, thus increasing their susceptibility to the toxic gas.

The earlier Monserco study was directed towards the development of a statistical model which predicts the probability of short-term lethal concentration peaks downwind of a release of $H_2S$ (or any toxic gas for which a lethal dose relationship is available for the exposure times of interest). The probability is shown to be a function of the downwind distance from the release, the "long-term" (10 minute average or longer) concentration, as predicted by Gaussian dispersion models, wind speed, atmospheric stability and terrain roughness. It was demonstrated that, in the case of $H_2S$, the probability of a lethal short-term concentration peak can be significant, even when the long-term average concentration is as low as 180 ppm (250 mg/m³).

It should be noted that the so-called peak-to-mean model referred to above predicts the probability of at least one fatality resulting from a given long-term average $H_2S$ concentration. Ideally, to perform a full consequence assessment, one would need to predict the number of fatalities per unit population exposed. This would require specification of the $LC_{50}$, $LC_{90}$, etc. for each of the lethal modes of action represented by the step function, i.e., a separate set of functions corresponding to each probability level. Unfortunately, neither the human nor animal data available can support such an exact quantitative description of $H_2S$ toxicity. This was confirmed by reference to a recent review by the Associate Committee on Scientific Criteria for Environmental Quality of the National Research Council of Canada (NRCC, 1981). However, what data that does exist suggests that the $LC_{50}$ level may be 2 to 3 times the threshold level for lethality, or the $LC_{min}$. It is recommended, therefore, that some numerical experiments be carried out to assess the sensitivity of the consequence assessment to the assumed $LC_{50}$'s, $LC_{90}$'s, etc. This would be done by using the Monserco (1981) peak-to-mean model for different downwind distance, weather and terrain roughness conditions to predict the probability that the $LC_{50}$, $LC_{90}$ levels would be exceeded by the largest short-term peak concentration. The results can then be presented as a cumulative distribution function of the percentage of fatalities under each set of assumptions. It is also recommended, on the basis of the literature (Monserco, 1981, NRCC, 1981) that the lethal threshold of 400 $mg/m^3$ (290 ppm) apply to long-term exposures up to 8 hours duration.

### 5.2 Toxicity of $SO_2$

In view of the fact that, under some circumstances, a release of $H_2S$ may be ignited and burn to $SO_2$ (see Section 3 of this report), and large quantities of the gas are potentially involved, the possibility must be considered that toxic concentrations of $SO_2$ may be present at ground level downwind of a release.

Engelhardt and Holliday (1981) conducted a literature review of the effects of exposure to $SO_2$ on behalf of the Atomic Energy Control Board. In summary, the symptoms reported in cases of acute exposure in industrial accidents were:

- eye irritation above about 20 ppm
- higher concentrations and continued exposure lead to corneal damage, bronchial constriction, pulmonary edema and hemorrhage.

- where concentrations are of the order of several hundred ppm, the above responses will cause dyspnea ( shortness of breath) and possible permanent debilitation of pulmonary function or death.
- short-term mortalities are associated with "exceptionally high level exposures"causing spasm and asphyxiation within a few minutes.
- a small but significant section of the population (about 10%) is at greater risk in the event of $SO_2$ exposure since the onset of spasm occurs at concentrations well below levels necessary to produce the same symptoms in the bulk of the population.
- it is speculated, but there is no evidence to support this, that deaths at very high concentration levels may be caused by direct neural action.

Engelhardt and Holliday present human lethal dose curves for short exposures based on experimental animal data and extrapolation of longer term exposure data. The curves are reproduced in Figure 15. A derived $LC_{50}$ curve is given as well as an excess mortality curve. It is suggested by the authors that this may be interpreted as an $LC_{min}$ curve applicable to individuals particularly sensitive to $SO_2$. It is noted that, in contrast to $H_2S$, the $LC_{min}$ values are typically some 2,000 to 5,000 times lower than the $LC_{50}$ values for corresponding exposure times. It was thought possible that the 15 ppm $SO_2$ level for a 10 second exposure could cause death in a very debilitated and sensitive individual, even though the projected $LC_{50}$ level is 10% (100,000 ppm).

From an examination of the lethal dose curves for $SO_2$, and considering the fact that any release of $SO_2$ from an ignited $H_2S$ jet would undergo considerable buoyant rise in the atmosphere, it is unlikely that the peak-to-mean effect would be significant in this case. Thus, only the long-term ground level concentrations (30 minutes to several hours, depending on the duration of the accident) would need to be considered in relation to the lethal dose values for the corresponding exposure time. Nevertheless, it is recommended that numerical experiments also be carried out to verify this conclusion using the Monserco (1981) model in a similar manner to that proposed above for $H_2S$. For this purpose, it will be necessary to approximate the continuous functions shown in Figure 15 by step functions. In view of the uncertainty surrounding the lethal dose relationships, this does not represent a significant departure. In particular, it is expected that results will be sensitive to the assumed $LC_{min}$ curve.

## 5.3 Indoor-Outdoor Concentration Relationship

Remaining indoors with doors and windows closed during a toxic gas emergency is generally recognized to afford a degree of protection to the person in the path of the gas by reducing the maximum concentration to which the individual is exposed and eliminating the peak-to-mean effect experienced in the open air. The building acts in such a way as to dampen the concentration-time function, as follows (Whittaker, 1980):

$$\tau_B \frac{d\overline{X}}{dt'} + \overline{X} = X(t') \qquad (67)$$

where $\tau_B$ is the building time constant, $\overline{X}$ is the inside average concentration, t' is the time after the toxic gas arrives at the building and X(t') is the time varying outdoor concentration. The building time constant is determined as the ratio of the volume to the infiltration rate or, alternatively, the inverse of the number of air changes per unit time. Whittaker then shows that for an exponentially varying X(t') of the form

$$X(t') = X(t'=0) \exp.(- \frac{t'}{\tau}) \qquad (68)$$

in which $\tau$ is the time constant of the blowdown, the indoor-outdoor concentration relationship is given by

$$\frac{\overline{X}}{X(t'=0)} = \frac{1}{(\frac{\tau_B}{\tau}-1)} \quad \exp\left(\frac{-t'}{t_B}\right) - \exp\left(\frac{-t'}{\tau}\right) \qquad (69)$$

In the present context, the maximum indoor concentration is the parameter of interest and this can be obtained by differentiating eqn.(69), to obtain:

$$t'_{max} = \frac{\ln(\frac{\tau_B}{\tau})}{(\frac{1}{\tau} - \frac{1}{\tau_B})} \qquad (70)$$

The maximum is then found by substituting for t' from eqn.(70) into eqn.(69).

The above model allows the simulation of the effect of remaining indoors while the plume from a transient release of $H_2S$ passes the receptor. This will generally be applicable to breaks greater than 0.15m (6 in) diameter (see Section 3.3). For implementation, it will require specification of building air change rates.

## 5.4 Population Data

The latest census year, for which population data has been compiled by statistics Canada, is 1981. In rural areas, such as the area of Bruce County near the heavy water plant, population statistics are routinely available according to different geostatistical areas, e.g. by city, town, township, village. The smallest area is the census tract (CT), but this is available only for urban settlements. Elsewhere, the smallest area is generally the provincial census tract (PCT), whose populations usually vary between 3,000 and 8,000. (1981 Census Dictionary, Statistics Canada.) In some cases, village, town or township subdivisions may yield more precise data.

For the purposes of consequence assessment in which postulated gas concentrations would vary rapidly with distance, particularly in the immediate vicinity of the heavy water plant, it is recommended that census data be requested from Statistics Canada for user-defined areas, i.e. for concessions and villages.

## 5.5 Modelling Requirements

The essential elements required in the model to predict receptor response have been discussed above. These are:

- lethal dose relationships for $H_2S$ and $SO_2$ for exposure times of several hours down to a few seconds. The functions should be specified for several probability levels, i.e. $LC_{50}$, $LC_{90}$, $LC_{min}$, etc.
- use of the Monserco (1981) peak-to-mean model to predict the short-term peak concentration, given an average concentration (10 minutes or more) generated by the plume or puff dispersion models.
- a separate model to predict maximum concentrations inside buildings for transient releases, following Whittaker (1980)
- population data in the area of the heavy water plant from Statistics Canada, preferably for individual concessions and villages, as well as census tracts in towns such as Kincardine.

The available toxicity data for $H_2S$ and $SO_2$ is not sufficient to support an analysis of fatalities among specific age and health groups within the population. The variation in response due to these factors is assumed to be included in the overall statistics, i.e., the $LC_{50}$, $LC_{90}$ levels. Thus, there is no justifiable need for population data broken down in this way.

## 6. Summary of Recommendations

### 6.1 General

The methodological framework proposed for the consequence assessments of $H_2S$ releases from heavy water plants was set out in Section 2 of this report. For a given release, or initiating event, the consequence is evaluated in terms of a probability distribution of the number of casualties. This, in turn, is calculated from the probability distribution of casualties under each set of weather conditions and the probability of the weather conditions occurring (see eqn.(4)).

There are three essential elements to the problem:

(a) specification of the initiating events,

(b) the route to the receptor followed by the gas once released, according to certain physical characteristics of the release, weather conditions and certain site specific factors,

(c) the response of the receptor as determined by the resulting downwind gas concentrations in relation to toxic levels and, collectively, as a function of the population density in the affected area.

Each element has been treated separately in this report. Specific models have been recommended to represent the different elements and sub-elements and the critical parameters identified, as summarized below.

### 6.2 Initiating Events

For the purposes of specifying the models to be used in subsequent stages, nine release scenarios have been identified as being representative of conceivable initiating events. A study of the credibility or probability of these events was beyond the scope of the present work.

The nine scenarios are:

(a) catastrophic failure of an enriching unit tower,

(b) non-burning or burning release from pipe breaks of

0.15 - 1.3 m (6 - 52 in) diameter,

(c) non-burning release from a 0.6m (24 in) manhole in enriching unit tower,

(d) non-burning release from pipe breaks of 0.05 - 0.1 m (2 - 4 in) diameter,

(e) catastrophic failure of $H_2S$ storage tank,

(f) failure of storage tank manhole,

(g) failure of liquid line or bottom nozzle in $H_2S$ storage area,

(h) catastrophic tank car failure,

(i) burning or non-burning dump to flare.

For each scenario, the characteristic parameters which are of interest in determining the route to the receptor have been listed, as follows:

(a) gas emissions (amount of $H_2S$ or $SO_2$),

(b) duration of release (few seconds to continuous),

(c) location of release with respect to ground level,

(d) location of release with respect to the actual point of rupture of the pipe or vessel,

(e) physical extent of the release following initial expansion behaviour, i.e. a jet or cloud,

(f) density of the release with respect to ambient air, again following initial expansion behaviour.

In order to specify these parameters, models and equations are presented for:

(a) gaseous $H_2S$ flowrate as a function of time (equations 8-10),

(b) length and width of the gaseous jet (equations 14-15)

(c) temperature and density of the gas/air mixture resulting from a catastrophic failure of a liquid $H_2S$ storage tank (equations 16 and 17),

(d) flowrate from a liquid line (equation 20)

In addition, a procedure is recommended, following Hardee and Lee (1975), to determine the $H_2S$ gas/air mixture ratio referred to in (c) above, as a function of the initial mass of liquid, area of the tank rupture and initial liquid temperature. This requires numerical solution of a two-phase flow problem and should be done for the specific case of $H_2S$ before consequence assessment of this class of initiating events is attempted. Further investigation and sensitivity analysis of the discharge coefficient as it affects $H_2S$ flow rate was also recommended.

A short review was carried out of the possibility of unconfined vapor cloud explosions (UVCE), due to the presence of $H_2S$ concentrations between the upper and lower explosive limits. Although such a possibility may exist at heavy water plants, it was concluded that a useful model to describe the phenomenon could not be developed within the context of the present study. Knowledge of the causes and effects of UVCE's is still rather limited and, in any event, any model would be primarily concerned with the prediction of blast damage rather than toxic gas effects on the public.

### 6.3 Route to Receptor

A large number of recommendations have been made in this report for the modelling of the initial gas behaviour and the subsequent transport and dispersion. The initial gas behaviour, in this study, is taken to mean the density and/or momentum dominated phases immediately following release to atmosphere, and specific equations are recommended to predict:

(a) momentum rise of vertical jet (eqns.24-27)

(b) buoyant plume rise due to a burning release, or flare, of $H_2S$ (eqns. 28-35)

(c) lift-off of a ground level buoyant release (eqns. 36-37)

(d) gravitational behaviour of a dense gas cloud (eqns. 38, 42, 44, 45, 51)

(e) transition of a dense cloud to passive cloud behaviour (eqn. 47)

(f) plant aerodynamic wake effects (eqns. 53 and 54, see also Lucas, 1962)

These models are intended to provide, as output, the effective release height and the effective cloud dimensions at the beginning of the passive transport and dispersion phase.

Gaussian plume and puff dispersion models are prescribed to represent, respectively, continuous and instantaneous or short-term releases, using in both cases:

(a) climatological $\sigma_y$ and $\sigma_z$ values developed from site-specific measurements of a $\sigma_\theta$ and $\sigma_\phi$ , where these are available, or

(b) Brigg's (1973) and Hosker's (1974) $\sigma_y$ and $\sigma_z$ functions, the latter for release heights less than 100 m.

Simple modifications of the Gaussian models to account for inversion trapping (Turner, 1970) are also recommended.

Since the consequence assessment model is to be applied first to the Bruce HWP, special consideration was given to site-specific factors which might influence dispersion at this site. The most significant effect is due to Lake Huron, specifically the generation of a day-time lake breeze circulation. Releases made into the relatively stable air aloft may be fumigated to ground level further inland by the thermal internal boundary layer (TIBL). It is recommended that a model by Lyons (1975) be implemented to simulate this effect. A secondary consideration is a small escarpment some 3.5 km E and NE of the plant. A simple model after Burt (1977) is recommended to include its effect on local ground level concentrations. It is proposed that the need for site-specific climatological data, primarily wind speed, direction and atmospheric stability frequency be met by using historical data from Wiarton and Goderich, adjusted according to a technique applied elsewhere by Baynes (1981). This will require that a limited amount of data (preferably a year) be obtained from the Bruce meteorological tower, i.e. winds at 10-100m and the vertical temperature profile.

Finally, a specific recommendation is made that a representative quantitative description of the lake breeze induced TIBL be developed for the Bruce site.

## 6.4 Receptor Response

The receptor response model would be built around the statistical "peak-to-mean" model developed earlier for the AECB by Monserco (1981), with the following modifications:

(a) specification of additional lethal dose step functions to represent $LC_{50}$, $LC_{90}$, $LC_{min}$ curves for both $H_2S$ and $SO_2$, over exposure times from 10 seconds to 8 hours.

(b) the $LC_{min}$ and $LC_{50}$ lethal dose functions for $SO_2$ to be based on Engelhardt and Holliday (1981)

(c) for each combination of initiating event, weather condition and downwind location, the probability of exceeding the $LC_{50}$, $LC_{90}$, $LC_{min}$ to be calculated and, from this, the probability distribution of fatalities.

It is recommended that numerical experiments be carried out to determine the sensitivity of the model to assumed lethal dose functions for both $H_2S$ and SO, i.e, the sensitivity to the step function approximations to Figures 14 and 15 respectively.

Further recommendations are that:

(a) a separate model be included to predict maximum concentrations inside buildings for transient releases, following Whittaker (1980)

(b) population data, preferably on individual concessions and villages, be requested from Statistics Canada.

## 6.5 Model Structure and Implementation

The overall synthesis of the different components of the consequence assessment model is illustrated in the attached chart (Figure 16). Wherever possible, individual modules should be programmed using existing FORTRAN routines. Specifically, we have been able to identify the following which conform to the modelling recommendations and are readily available for adaptation for the present purposes:

(a) Heavier-than-air gas behaviour and transition to passive behaviour (from DENZ-Fryer and Kaiser (1979) - already obtained by AECB.

(b) Statistical peak-to-mean model (Monserco (1981) - developed for AECB)

(c) Grid definition module (Monserco library)

(d) Gaussian plume dispersion with trapping (Monserco library)

(e) Buoyant plume rise (Monserco library)

(f) Terrain adjustment (from EPA VALLEY model)

Because of the complexity of the proposed model, it has not been possible to estimate with any accuracy the likely run costs. However, our experience with codes of a similar size suggest an order of magnitude of some $500. per run based on 120 minutes of CPU time and including likely connect and I/O charges.

## 6.6 Terms of Reference for Continuing Study

The work described in this report was intended as the first step in a two phase program. The second and third steps of the first phase will be concerned with the implemention of the consequence assessment model and the second phase with its application to a number of postulated initiating events, including a sensitivity analysis.

The recommendations summarized above are intended to provide the necessary definition of the model to be implemented, and the release scenarios to be examined. However, the specific tasks to be performed are recommended below. It should be noted that steps 2 and 3 are separated to allow parallel review by the AECB of the initiating events and the initial treatment of release behaviour, while the more straightforward atmospheric dispersion and receptor response model components are being assembled.

### 6.6.1 Implementation of Dispersion and Receptor Response Models (Step 2)

(a) establish and test the Gaussian plume and puff dispersion modules with provision for alternative $\sigma$ functions as recommended

(b) incorporate the inversion trapping and terrain modifications as recommended, and test,

(c) establish and test the lake breeze fumigation module based on the model of Lyons (1975)

(d) make recommended modifications to the Monserco (1981) peak-to-mean model and test, including the incorporation of $LC_{50}$, $LC_{90}$ functions for $SO_2$ and $H_2S$ and the calculation of consequence distribution functions.

(e) implement model for determining peak concentrations inside buildings as recommended.

(f) obtain off-site historical and site specific meteorological data for later analysis in Phase 2, including information required to develop description of the lakebreeze TIBL

(g) obtain population data as recommended

(h) program overall model with respect to module interactions, inputs and outputs (see Figure 16).

(i) review of the present report with AECB and determination of scope of work for Step 3, including initiating events to be handled by the model.

6.6.2 Implementation of Initial Effects Models (Step 3)

(a) Specify for each initiating event, the necessary characteristic parameters required as input to the model. (Suitable models and equations to achieve this are recommended in this report.)

(b) Establish and test modules to simulate initial gas behaviour, as recommended, for
    (i) momentum rise of overhead jet
    (ii) buoyant plume rise
    (iii) lift-off
    (iv) dense cloud behaviour
    (v) transition of dense to passive cloud
    (vi) plant aerodynamic wake effects.

(c) Perform test runs with complete model for specified initiating events (incomplete or preliminary input data may be used for this purpose).

(d) Document the completed model results of test runs and data files established in steps 2 and 3.

### 6.6.3 Consequence Assessments (Phase II)

(a) Review the report on steps 2 and 3 of Phase I and define, in conjunction with AECB, the initiating events to be studies in Phase II.

(b) As recommended, develop the model to determine the $H_2S$ gas/air mixture ratio following a catastrophic failure of a liquid storage tank.

(c) Develop for the Bruce site the site-specific dispersion climatology and the representative lake breeze TIBL model as recommended.

(d) Perform a sensitivity analysis of the model to the critical variables identified in this report.

(e) Make final selection of model parameters based on results of sensitivity analysis and "best estimate" philosophy.

(f) Perform consequence assessments and report results.

(g) In view of rapid developments in this relatively new field, particularly in Europe, establish contact with workers in this field and, if necessary recommend modifications to the model in the final report.

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| | | kg $H_2S$ | % |
|---|---|---|---|
| Cold Section | liquid | 6300 | 7.0 |
| | gas | 46400 | 51.4 |
| Hot Section | liquid | 2000 | 2.2 |
| | gas | 35500 | 39.4 |
| TOTAL........................... | | 90200 | 100.0 |

TABLE 1

BREAKDOWN OF $H_2S$ INVENTORY OF FIRST STAGE ENRICHING UNIT TOWER (ADAPTED FROM PORT HAWKESBURY HWP SAFETY ANALYSIS)

| LOCATION | QUANTITY (TONNES) | PHYSICAL STATE |
|---|---|---|
| Enriching Units (4)<br>incl. interconnecting pipes and associated equipment | 2160 | Approx. 90% as gas at 2080 kPa<br>Approx. 51% at 32°C and 39% at 128°C |
| $H_2S$ storage and unloading area | 1130 | Liquid at saturated conditions (2720 kPa, 38°C) |
| $H_2S$ Recovery Area | 100 | Primarily gas |
| Interconnecting pipes | <1 | Primarily gas at 2350 kPa. |
| TOTAL | 3390 | |

TABLE 2

SUMMARY OF ESTIMATED $H_2S$ INVENTORY

FOR BRUCE HWP (A AND B)

| | Scenario | Location of Release | Gas Release Rate |
|---|---|---|---|
| 1. | Emergency dump to flare stack with failure to ignite | Flare stack at 145 m | 145 kg/s $H_2S$ |
| 2. | Non burning releases from pipe breaks<br>-0.05 m (2 in)<br>-0.10 m (4 in)<br>-0.15 m (6 in) | Piperack, elevation 22m | <br>10.5 kg/s $H_2S$<br>40 kg/s $H_2S$<br>94 kg/s $H_2S$<br>(based on single-ended breaks with coefficient of discharge of 1.0- double values for guillotine breaks) |
| 3. | Liquid spill in $H_2S$ storage area due to failure of 0.05m bottom nozzle | Ground level | 75 kg/s $H_2S$ vapour |
| 4. | Nonburning release from 0.6m (24 in) manhole | 38m<br>111m | 1,135 kg/s maximum decreasing with time |

TABLE 3

SUMMARY OF GAS RELEASE SCENARIOS

(BRUCE HWP SAFETY REPORT,

1980 and 1982 (draft))

| Scenario | Location of Release | Configuration |
|---|---|---|
| 1. Catastropic failure of enriching unit tower | Ground level to 110 m | -- |
| 2. Non-burning or burning releases from enriching unit interconnection lines<br>- 1.3m (52 in)<br>- 1.1m (42 in)<br>- 0.6m (24 in) | Ground level to ~ 110m | Single or double-ended, pipe vertical or horizontal |
| 3. Non-burning or burning release from 0.6m (24 in) manhole in enriching unit tower | ~ 7-80m above grade | Manhole vertical |
| 4. Non-burning or burning release from pipe breaks<br>- 0.05m (2 in)<br>- 0.01m (4 in)<br>- 0.15m (6 in)<br>- 0.3 m (12 in) | Ground level to ~ 10m | Single or double-ended, pipe horizontal or vertical |
| 5. Catastrophic failure of $H_2S$ storage tank | Ground level | Flashed vapour cloud |
| 6. Failure of storage tank manhole, 0.6m (24 in) | ~ 4m | Manhole horizontal, flashed vapour cloud |
| 7. $H_2S$ storage area failure of liquid line or bottom nozzle | ~ ground level | Gas released from flashing jet of liquid |
| 8. Catastrophic tank-car failure | ~ ground level | |

TABLE 4

| | Scenario | Location of Release | Configuration |
|---|---|---|---|
| 9. | Dump to flare stack with or without burning | 145 m | |

TABLE 4

SUMMARY OF GAS RELEASE SCENARIOS -
EXPANDED LIST FOR MODEL SPECIFICATION
PURPOSES ONLY

| | |
|---|---|
| Molecular Weight (g/mole) | 34.08 |
| Melting Point (°C) | -82.9 |
| Boiling Point (°C) | -61.8 |
| Density (g/L at 0°C and 101.3 kPa) | 1.539 |
| Sound Speed (m/s) | 289 |
| Vapour pressure, (kPa at temp in °C) | 1094 @0; 1875 @20; 3009 @40; 4509 @60; 6485 @80; 6988 @100 |
| Solubility (in water, g/100g per 101.3 kPa at temp in °C) | 4.95 @0; 8.77 @30; 13.2 @40; 17.8 @60; 22.8 @80; 24.7 @100 |
| Heat of combustion (kJ/kg) | 15,300 |
| Ignition temp. (°C) | 260 |
| Explosion range | 4-44% by volume in air |

TABLE 5

PHYSICAL-CHEMICAL PROPERTIES OF $H_2S$

(from NRCC, 1981 and Weast, 1982)

| BREAK DIAMETER (m) | (in) | TIME CONSTANT (s) | INITIAL RELEASE RATE (kg/s) |
|---|---|---|---|
| 0.05 | 2 | $1.58 \times 10^5$ | 9.33 |
| 0.10 | 4 | $2.28 \times 10^4$ | 37.3 |
| 0.15 | 6 | $7.12 \times 10^3$ | 83.8 |
| 0.3 | 12 | $1.14 \times 10^3$ | 335 |
| 0.6 | 24 | $2.85 \times 10^2$ | 1340 |
| 1.1 | 42 | 84.7 | 4520 |
| 1.3 | 52 | 60.6 | 6290 |

NOTES:

1. Assumed discharge occurs from single first stage tower, volume 5000 $m^3$, $H_2S$ inventory 120 tonnes, initial temperature 353K and pressure 2080 kPa.

2. Empirical corrections applied to blowdown time constant 0.05m - 0.26, 0.10m - 0.45, 0.15m - 0.64, other break sizes - 1.0.

3. No discharge coefficient applied to release rate.

4. Release rates from singe-ended breaks-double values for guillotine breaks.

TABLE 6

TYPICAL $H_2S$ RELEASE RATES AND

DISCHARGE TIME CONSTANTS

| SCENARIO | EMISSIONS | DURATION | ELEVATION | LOCATION | EFFECTIVE PHYSICAL EXTENT | DENSITY | NOTES |
|---|---|---|---|---|---|---|---|
| 1. Catastrophic failure of Enriching Unit tower | Total tower $H_2S$ inventory e.g. 120 tonnes | Few seconds | Ground level to ~110m | At rupture | Cloud 100's of meters, from Hardee & Lee (1975) | Neutrally buoyant cloud from Haddock & Williams (1978) Eqns (16) & (17)* | *Modified according to tower and ambient temperatures |
| 2. a) Non-burning release from pipe breaks. 0.15-1.3m (6-52in) dia.<br>b) burning release from same source | Initially 83.8-6290 kg/s $H_2S$ depending on break size (single-ended breaks) | 1000's to 10's of seconds depending on break size | Ground level to ~110m | 10's of metres from break at end of jet phase, See eqns. (14) & (15) | Jet metres in diameter | a) Neutrally buoyant cloud of $H_2S$/air following jet<br>b) Buoyant $SO_2$ / air cloud following jet | Single or double ended break. Gas jet horizontal or vertical. |
| 3. a) Non-burning release from 0.6m (24in) manhole in enriching unit tower | Initially 1340 kg/s $H_2S$ | 100's of seconds | 7 to 80m above grade | 100's of metres from break at end of jet phase see eqns. (14) & (15) | Jet 10's of metres in diamter | a) Neutrally buoyant cloud of $H_2S$/air following jet<br>b) Buoyant $SO_2$/ air and cloud following jet | Jet horizontal |
| 4. Non-burning release from pipe breaks. 0.05-0.1m (2-4in) dia. | 9.3-37.3 kg/s (single-ended breaks) | Continuous | ground level to 110m | 10's of metres from break at end of jet phase see eqns. (14) & (15) | Jet metres in diameter | Neutrally buoyant cloud of $H_2S$/air following jet | Single or double ended break. Gas jet horizontal or vertical |
| 5. Catastrophic failure of $H_2S$ storage tank | Total $H_2S$ inventory e.g. 180 tonnes | Few seconds | ground level | At rupture | Cloud 100's of metres dia. From Hardee & Lee (1975) | Dense cloud from Haddock and William (1978) Eqns (18) & (19)* | *Modified according to storage and ambient temperatures |

CONTINUED............

TABLE 7

| SCENARIO | EMISSIONS | DURATION | ELEVATION | LOCATION | EFFECTIVE PHYSICAL EXTENT | DENSITY | NOTES |
|---|---|---|---|---|---|---|---|
| 6. Failure of storage tank manhole | Initially 1340 kg/s $H_2S$ | 100's of seconds | 4m | 100's of metres from break at end of jet phase see eqns (14) & (15) | Jet 10's of metres in diameter | Neutrally buoyant cloud of $H_2S$/air following jet | Vertical jet |
| 7. $H_2S$ storage area-failure of liquid line or bottom nozzle | 137 kg/s $H_2S$ (based on 0.05m dia line - single ended break) | Continuous | ground level | Close to point of rupture | Jet metres in diameter | Dense vapour cloud. Eqn. (18)&(19)* | *$H_2S$/air mixture must be obtained from jet behaviours |
| 8. Catastrophic tank car failure | Total $H_2S$ inventory e.g. 46 tonnes | Few seconds | ground level | At rupture | Cloud 100's of metres diameter From Hardee & Lee (1975) | Dense cloud from Haddock & Williams Eqns (18) & (19)* | *Modified according to storage and ambient temperatures |
| 9. Dump to flare<br>a) without burning<br>b) burning | 83.8 kg/s* | 1000's of seconds | 145m | Flare stack | Point source | a) Neutrally buoyant cloud of $H_2S$<br>b) Buoyant flare of $SO_2$ | *Based on flow through 0.15m (6 in) emergency dump valve |

TABLE 7

SUMMARY OF RELEASE CHARACTERISTICS

## TABLE 8

## SUMMARY OF MODELLING REQUIREMENTS

## TO DESCRIBE ROUTE TO RECEPTOR

| PHENOMENON | MODEL | INPUT | OUTPUT | NOTES |
|---|---|---|---|---|
| (1) Momentum rise of vertical jet | Eqns (24-27) | Initial jet velocity & diameter, momentum flux, windspeed, atmospheric stability | Momentum rise (effective release elevation) | |
| (2) Buoyant plume rise due to burning release of $H_2S$ | Eqns (28-35) | *$H_2S$ emission rate, wind speed, atmospheric stability | Buoyant rise (effective release elevation) as function of downwind distance | *Required to calculate buoyancy flux due to heat of combustion See Eqn (35) |
| (3) Buoyant plume lift-off | Eqns (36-37) | Cloud vertical size and density, ambient air density, wind speed, terrain roughness length | *Criterion determines if lift-off occurs | *Applies to releases initially at ground level. If lift-off does not occur, treat as ground level release |
| (4) Gravitational behaviour of dense gas cloud | Eqns (38,42, 44,45,51) | Initial cloud density height and radius. Ambient air density, typical turbulent velocity, Richardson number (atmospheric stability) | Cloud height and radius as a function of time | |
| (5) Transition of dense to passive gas cloud | *Eqn (47) | Cloud density and height. Atmospheric stability, wind speed | +Transition point. Cloud height and radius at transition | *Alternatively, compare cloud and ambient air densities.<br>+Cloud growth downstream of transition given by eqns (48) & (49) |

TABLE B CONTINUED

| PHENOMENON | MODEL | INPUT | OUTPUT | NOTES |
|---|---|---|---|---|
| (6) Plant wake effect | (a) For wake entrainment, Fig. (Lucas, 1962)<br>(b) For cavity entrainment (release height ≤1.6 obstacle heights) Eqns (53) & (54) | Height of gas release, obstacle dimensions | (a) Effective release height<br>(b) Cloud growth downstream of cavity | Passive releases only |
| (7) Dispersion of passive<br>(a) plume* or<br>(b) puff | (a) Eqn (59)<br>(b) Eqn (60)<br>Modification for inversion trapping, see Turner (1970) | Gas release rate (plume) or total release (puff), wind speed, atmospheric stability, mixing height. Dispersion coefficients from eqns (64) and (65) or Briggs (1973) and Hosker (1974)+ | Ground level concentration as function of distance downwind and crosswind location. Also as function of time for puff. | After inital buoyancy or momentum dominated phase.<br>*Release time > travel time to receptor.<br>+Release heights < 100m only |
| (8) Dispersion over elevated terrain (Bruce HWP) | Burt (1977) | Terrain elevation | | Stable atmospheres only. Adjustment applied to eqns (59) and (60) |
| (9) Fumigation of elevated release due to lake breeze (Bruce HWP) | Lyons (1975) | Wind speed, stable layer and TIBL stability, TIBL height versus distance inland | Ground level concentration as function of distance inland and crosswind location | |

| CONCENTRATION |  | EFFECTS |
|---|---|---|
| (ppm) | (mg/m$^3$) |  |
| 0.001 |  | Odour threshold for more sensitive individuals. |
| 10 |  | Strong odour |
| 50 | 70 | Irritation of eyes and respiratory tract,conjunctivitis, keratitis, photophobia after several hours. |
| 100 | 140 | Sense of smell lost after a few minutes. Rhinitis, bronchitis, pulmonary edema from repeated or prolonged exposure. Hemorrhage and death possible within 48 hours. Slight systemic effects. |
| 250 | 350 | Hemorrhage and death within a few hours. Symptoms of CNS depression; headache, nausea, sensory and motor impairment, possibly leading to unconsciousness. |
| 500 | 700 | Acute, systemic effects dominate. CNS stimulation; increased respiration rate followed by respiratory arrest and possible death within a few minutes. |
| 1000 | 1400 | Lethal within a breath or two. |

**TABLE 9**

**SUMMARY OF HEALTH EFFECTS OF $H_2S$**

**(MONSERCO, 1981)**

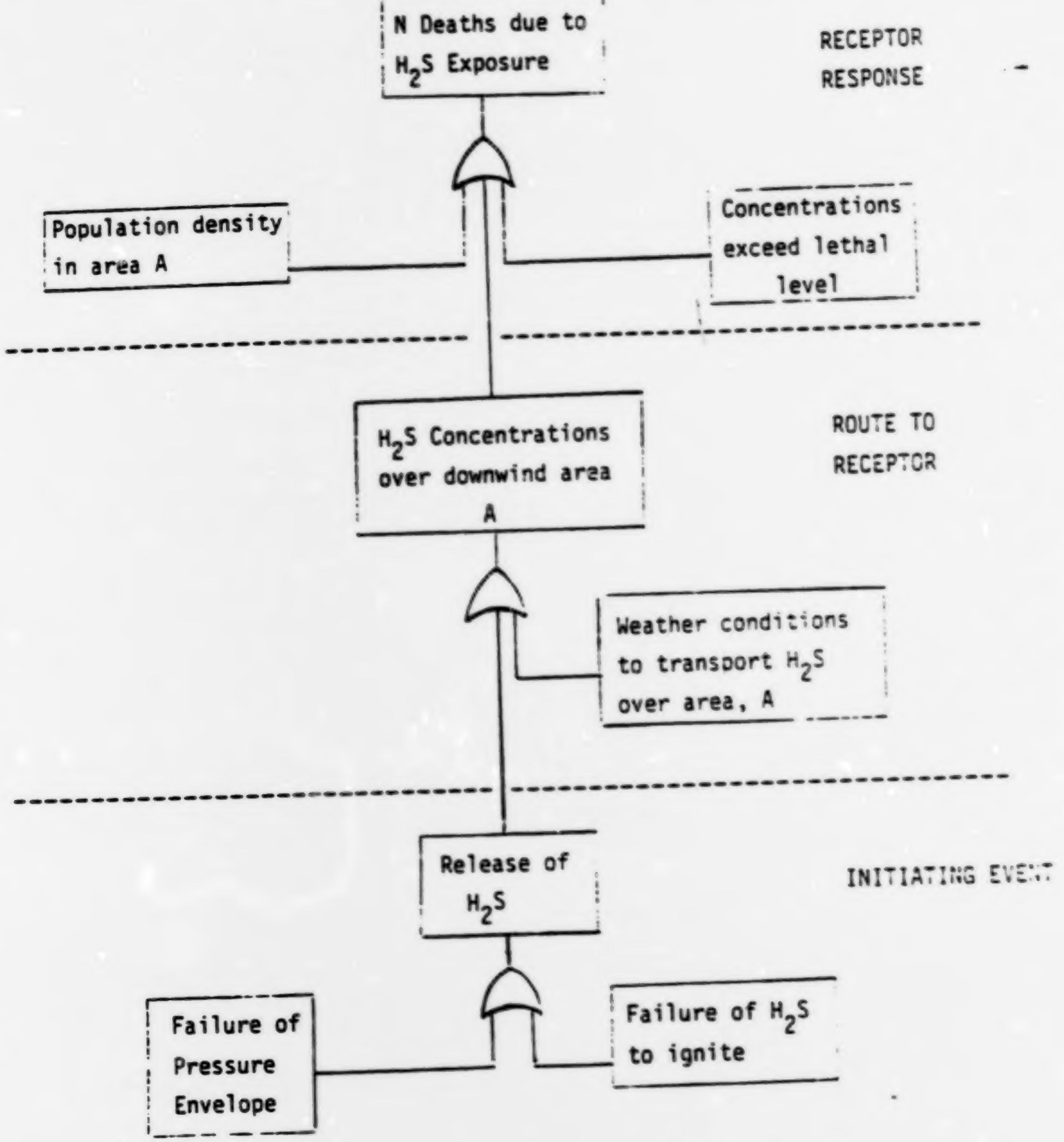
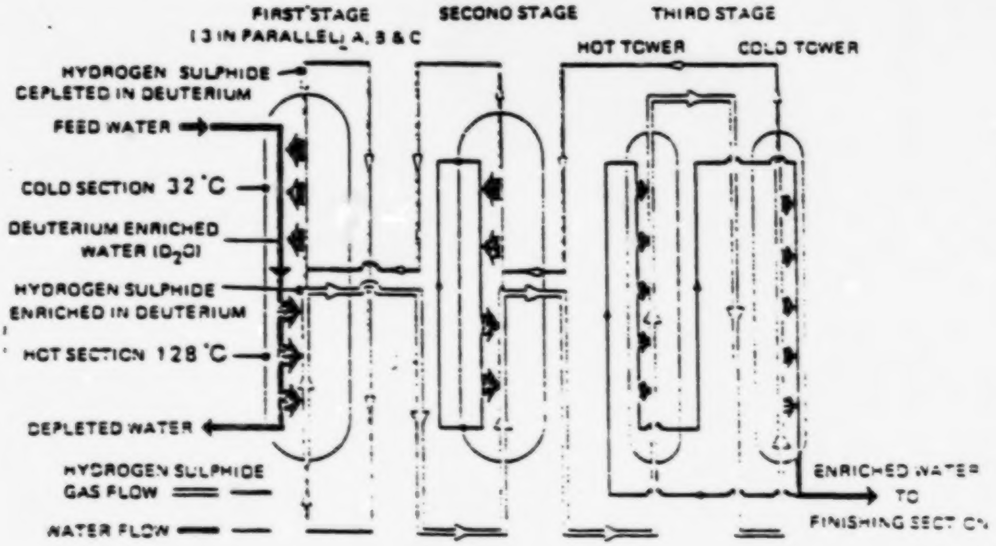
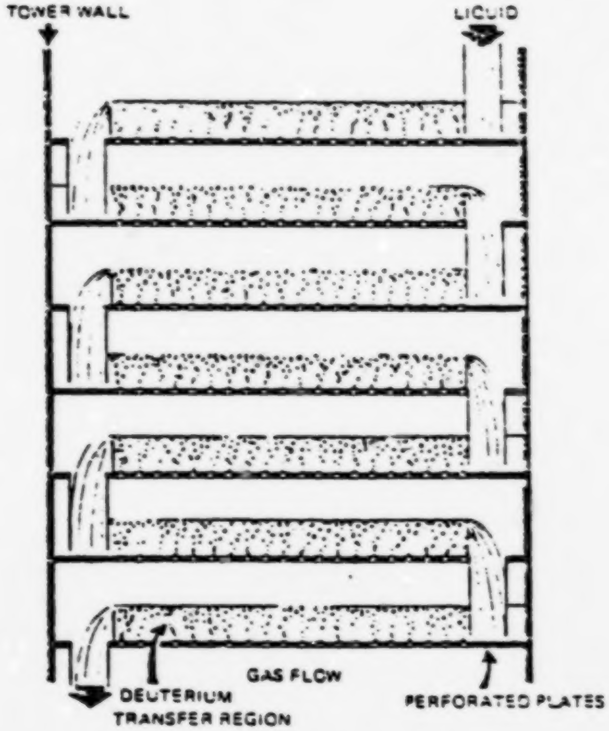

N Deaths due to H2S Exposure
RECEPTOR RESPONSE
Population density in area A
Concentrations exceed lethal level
H2S Concentrations over downwind area A
ROUTE TO RECEPTOR
Weather conditions to transport H2S over area, A
Release of H2S
INITIATING EVENT
Failure of Pressure Envelope
Failure of H2S to ignite

FIGURE 1

SIMPLIFIED FAULT TREE FOR FATALITIES DUE TO ATMOSPHERIC RELEASE OF $H_2S$


FIRST STAGE
(3 IN PARALLEL) A, B & C
SECOND STAGE
THIRD STAGE
HOT TOWER
COLD TOWER
HYDROGEN SULPHIDE DEPLETED IN DEUTERIUM
FEED WATER
COLD SECTION 32 °C
DEUTERIUM ENRICHED WATER (D2O)
HYDROGEN SULPHIDE ENRICHED IN DEUTERIUM
HOT SECTION 128 °C
DEPLETED WATER
HYDROGEN SULPHIDE GAS FLOW
WATER FLOW
ENRICHED WATER TO FINISHING SECTION

ENRICHING PROCESS

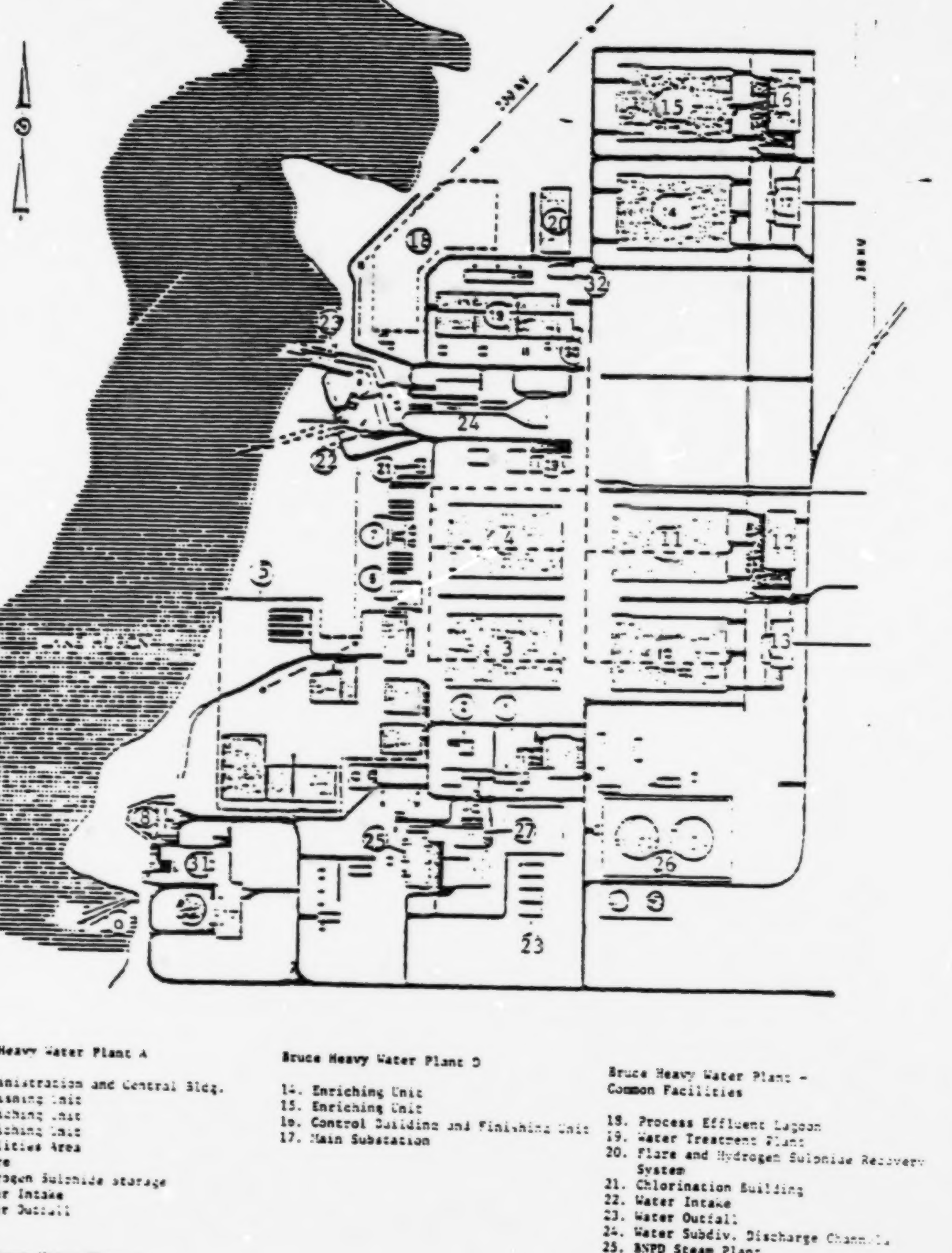

TOWER WALL
LIQUID
GAS FLOW
DEUTERIUM TRANSFER REGION
PERFORATED PLATES

TYPICAL GAS WATER FLOW THROUGH A TOWER

ENRICHING UNIT SIMPLIFIED FLOW DIAGRAM

(from Part I, Bruce HWP Safety Report,
Ontario Hydro, 1978)

FIGURE 2



**Bruce Heavy Water Plant A**

1. Administration and Central Bldg.
2. Finishing Unit
3. Enriching Unit
4. Enriching Unit
5. Utilities Area
6. Flare
7. Hydrogen Sulphide storage
8. Water Intake
9. Water Outfall

**Bruce Heavy Water Plant B**

10. Enriching Unit
11. Enriching Unit
12. Control Building and Finishing Unit
13. Main Substation

**Bruce Heavy Water Plant D**

14. Enriching Unit
15. Enriching Unit
16. Control Building and Finishing Unit
17. Main Substation

**Bruce Heavy Water Plant - Common Facilities**

18. Process Effluent Lagoon
19. Water Treatment Plant
20. Flare and Hydrogen Sulphide Recovery System
21. Chlorination Building
22. Water Intake
23. Water Outfall
24. Water Subdiv. Discharge Channels
25. BNPD Steam Plant
26. Oil Storage Tanks
27. Steam Condensate Building
28. Standby Generators
29. Laboratory Building
30. Common Services Control Building
31. Douglas Point Generating Station
32. Acid Storage Area

FIGURE 3

BRUCE HWP LAYOUT

(FROM BRUCE HWP SAFETY REPORT

SECTION I, ONTARIO HYDRO, 1978)

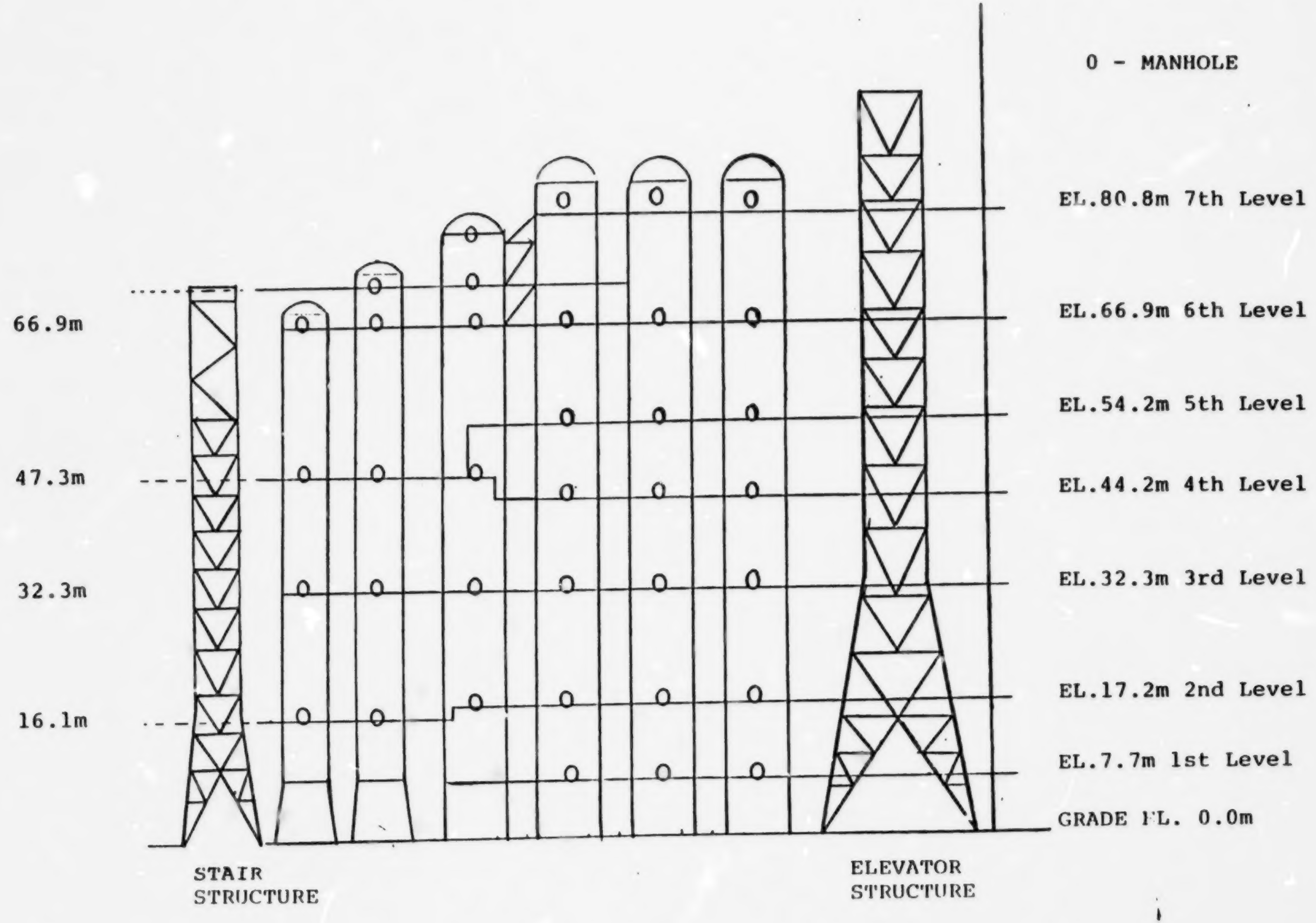
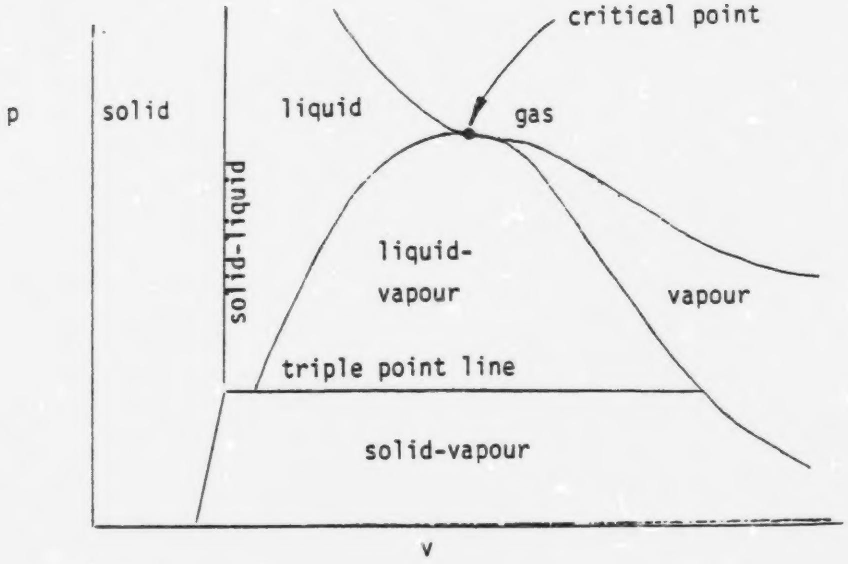

0 - MANHOLE
EL.80.8m 7th Level
EL.66.9m 6th Level
EL.54.2m 5th Level
EL.44.2m 4th Level
EL.32.3m 3rd Level
EL.17.2m 2nd Level
EL.7.7m 1st Level
GRADE FL. 0.0m
66.9m
47.3m
32.3m
16.1m
STAIR STRUCTURE
ELEVATOR STRUCTURE

FIGURE 4

SCHEMATIC ELEVATION OF BRUCE 'A' HWP ENRICHING UNIT


critical point
p
solid
liquid
gas
solid-liquid
liquid-
vapour
vapour
triple point line
solid-vapour
v

Critical temp (K) 373.6

Critical pressure (kPa) 9010

Critical molar volume ($dm^3$/mol) 0.09771

Triple point temp (°C) -85.75

Triple point pressure (kPa) 22.69

Latent heat of vaporization (KJ/mol) 18.67
at normal boiling point

Cp (ideal gas) at triple point, J/mol K 33.37

Ratio of specific heats 1.32

FIGURE 5

THERMOPHYSICAL PROPERTIES
OF $H_2S$

(after Neuburg et al, 1977)

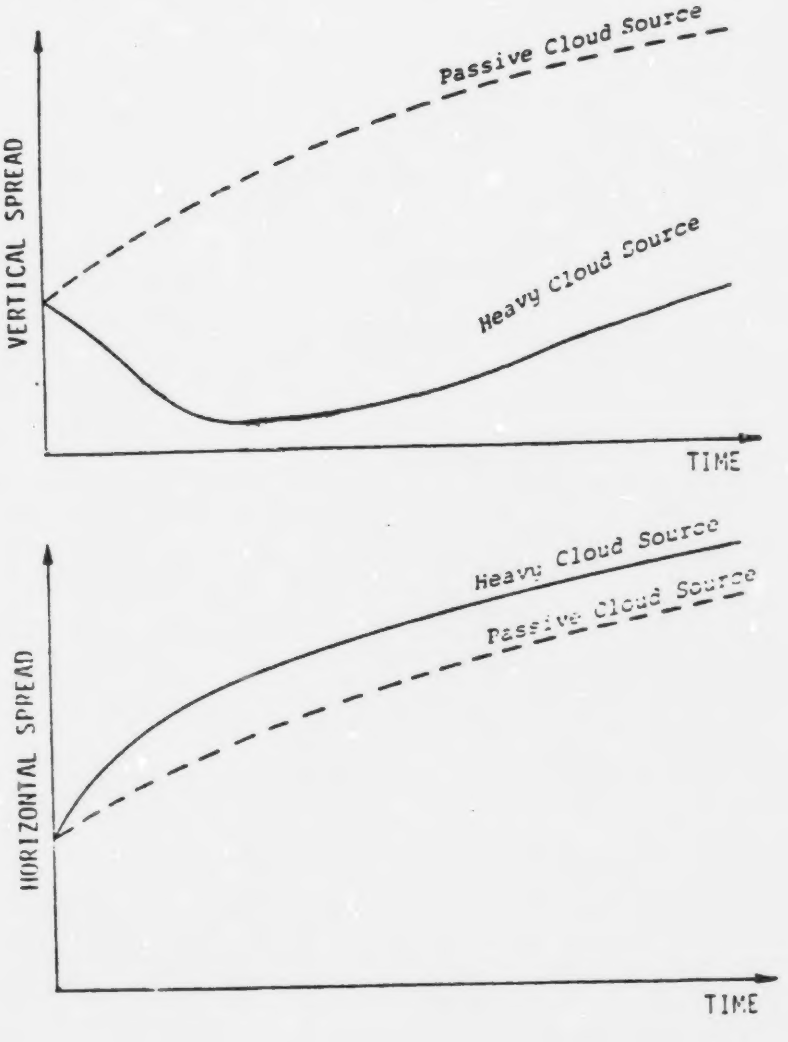


FIGURE 6: SPREADING RATES OF HEAVY GAS CLOUD COMPARED WITH PASSIVE CLOUD (AFTER REID, 1980)

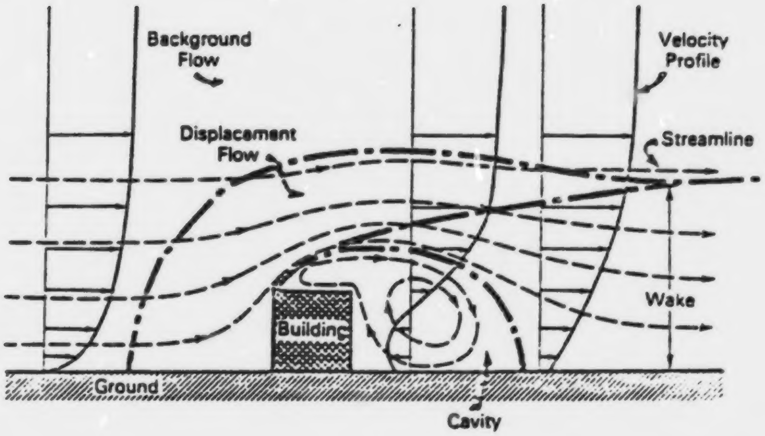

Background Flow
Velocity Profile
Displacement Flow
Streamline
Building
Wake
Ground
Cavity

FIGURE 7

TYPICAL FLOW REGIME OVER OBSTACLE

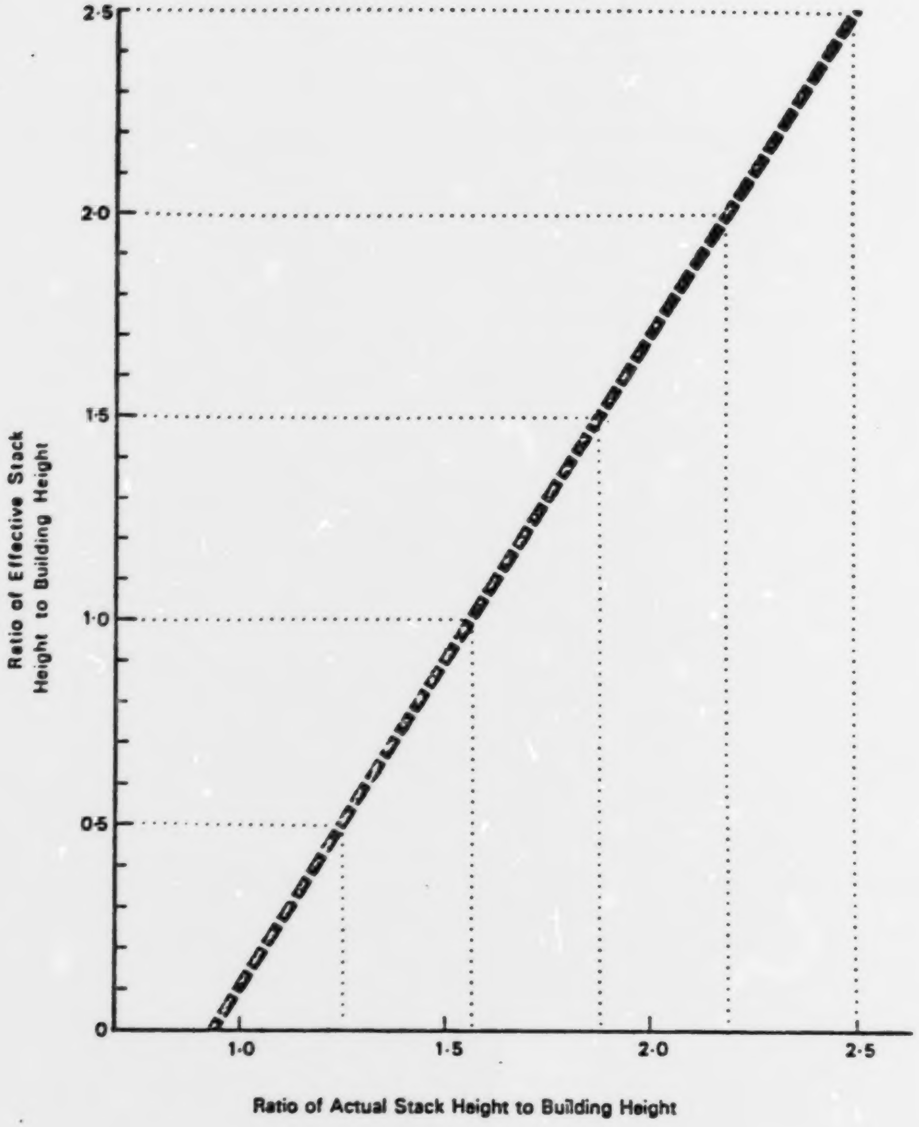
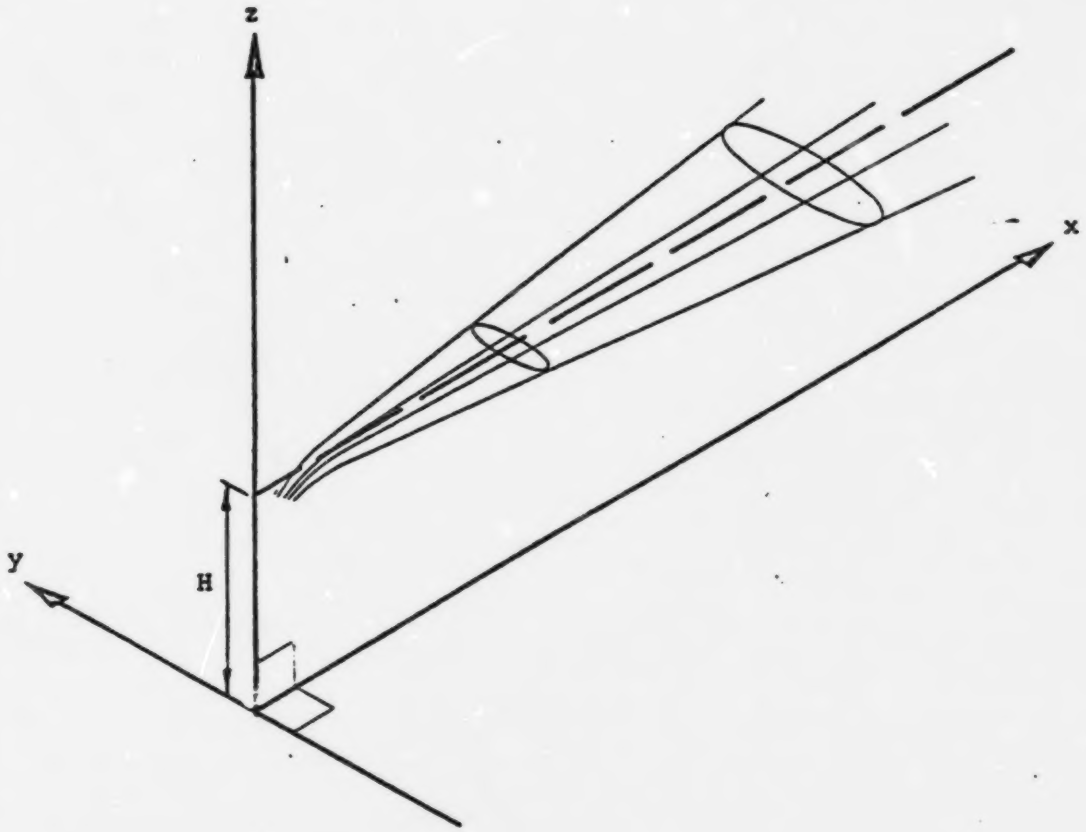


FIGURE 8

EFFECTIVE STACK HEIGHT RELATIONSHIP
(LUCAS, 1962)



$$X(x,y,z,H) = \frac{Q}{2\pi\sigma_y\sigma_z u} \exp\left[-\tfrac{1}{2}\left(\frac{y}{\sigma_y}\right)^2\right]$$

$$\exp\left[-\tfrac{1}{2}\left(\frac{z-H}{\sigma_z}\right)^2\right] + \exp\left[-\tfrac{1}{2}\left(\frac{z+H}{\sigma_z}\right)^2\right] \qquad (39)$$

where $X$ = concentration

$Q$ = release rate

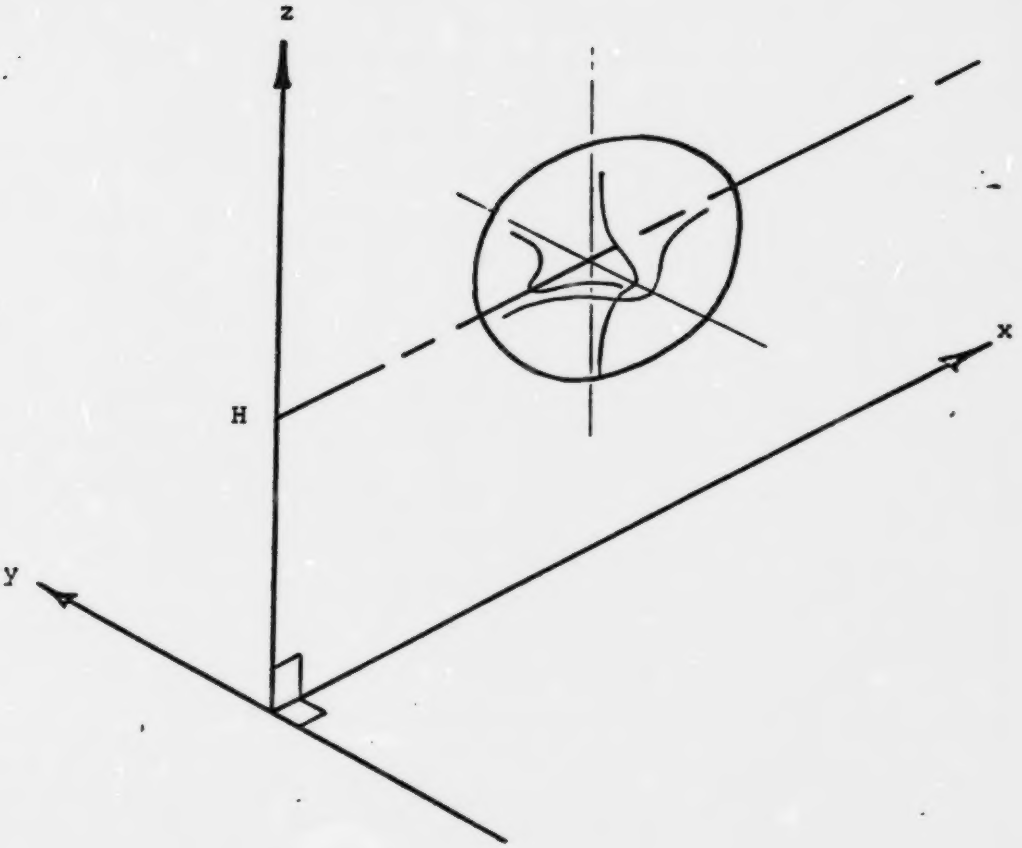
$u$ = wind speed

$H$ = effective release height

$\sigma_y, \sigma_z$ = standard deviations of concentration in lateral and vertical directions respectively (dispersion coefficients)

FIGURE 9

THE GAUSSIAN PLUME MODEL



$$X\ (x,y,z,t;H) = \frac{Q_T}{(2\pi)^{3/2}\sigma_x\sigma_y\sigma_z}\ \exp\left\{-\tfrac{1}{2}\left(\frac{Y}{\sigma_y}\right)^2\right\}$$

$$\times \left\{\exp\left\{-\tfrac{1}{2}\left(\frac{z-H}{\sigma_z}\right)^2\right\} + \exp\left\{-\tfrac{1}{2}\left(\frac{z+H}{\sigma_z}\right)^2\right\}\right\} \qquad (60)$$

$$\times \left\{\exp\left\{-\tfrac{1}{2}\left(\frac{x-ut}{\sigma_x}\right)^2\right\}\right\}$$

where $X$ = instantaneous concentration

$Q_T$ = total mass of release

$H$ = effective release height

$\sigma_x, \sigma_y, \sigma_z$ = standard deviaitons of concentration in a longwind, lateral and vertical directions respectively.

FIGURE 10

THE GAUSSIAN PUFF MODEL

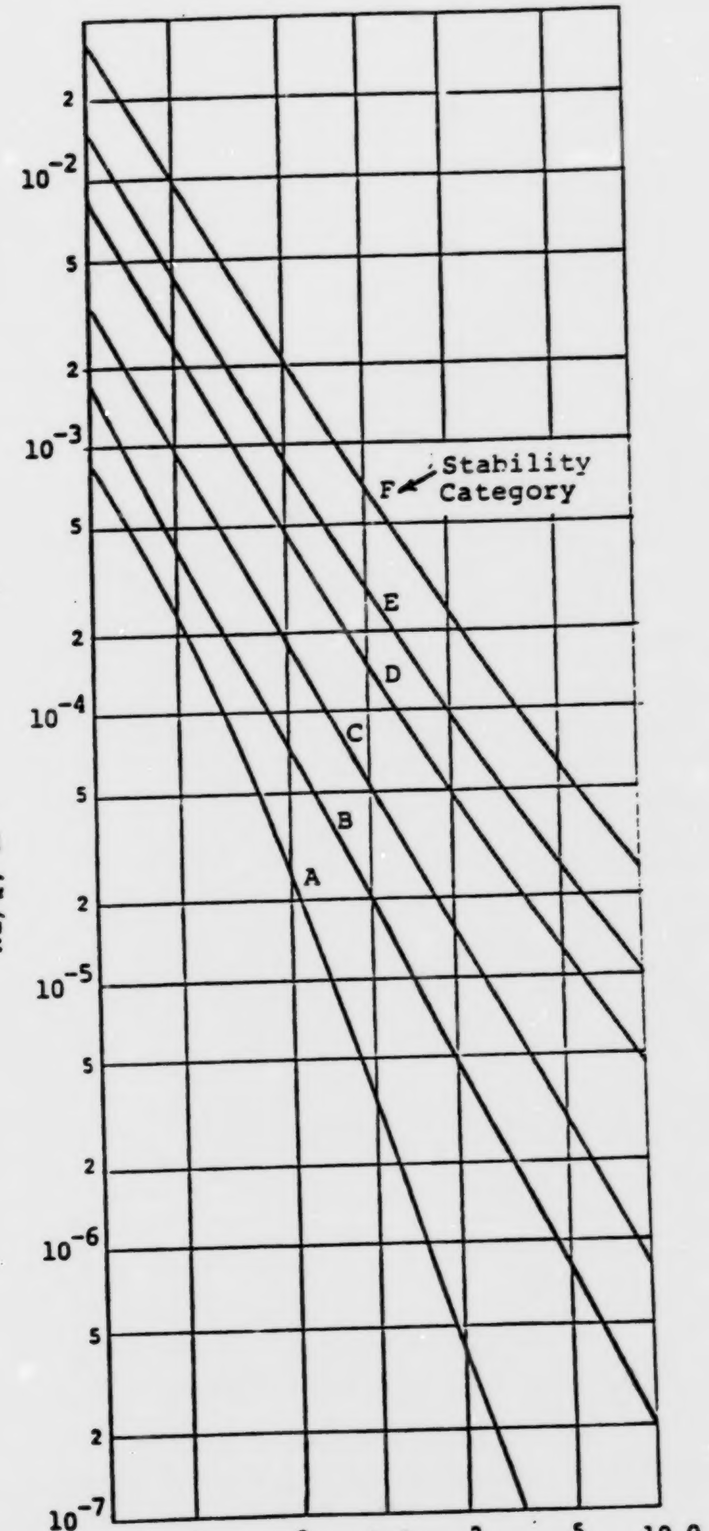
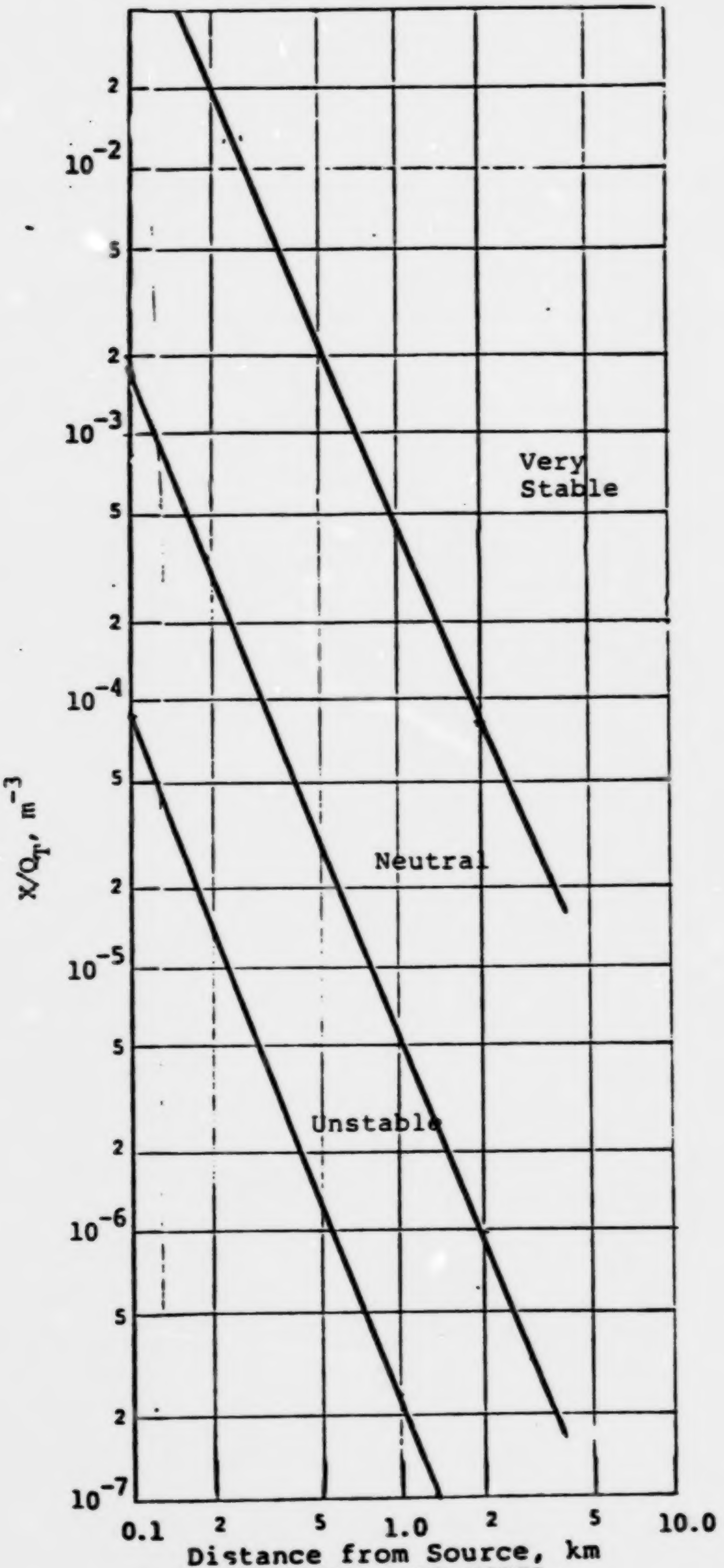


FIGURE 11 : GAUSSION PLUME MODEL: CONCENTRATION FACTOR Xu/Q VERSUS DOWNWIND DISTANCE FROM A GROUND LEVEL SOURCE



GAUSSIAN PUFF MODEL:
FIGURE 12: PEAK CONCENTRATION FACTOR $X/Q_T$ VERSUS DOWNWIND DISTANCE FROM A GROUND LEVEL SOURCE

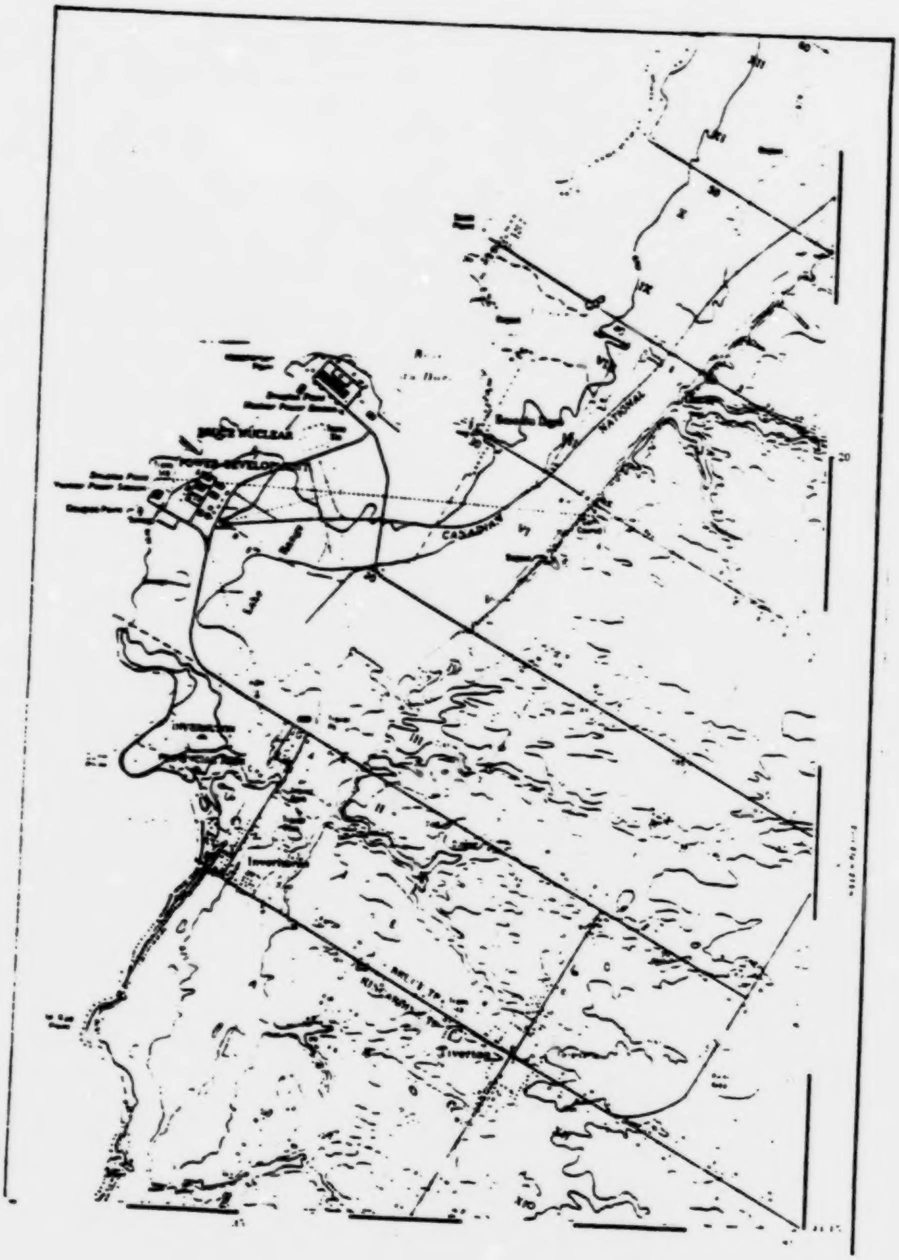

BRUCE NUCLEAR
POWER DEVELOPMENT
CANADIAN
NATIONAL
Inverhuron
Tiverton
20

FIGURE 13: MAP OF VICINITY OF BRUCE HWP
(APPROX. SCALE 1cm = 700m)

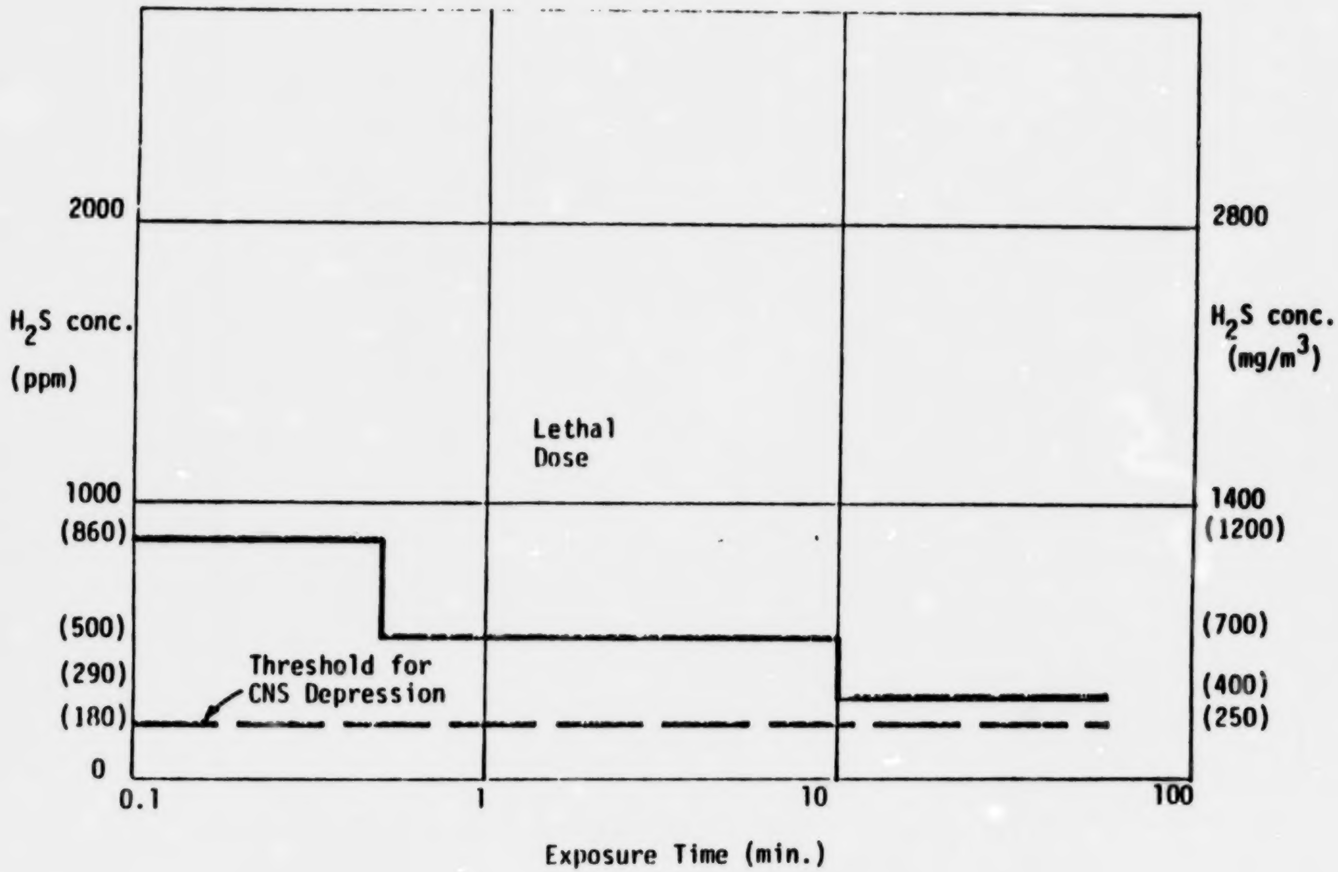


FIGURE 14: DERIVED $H_2S$ LETHAL DOSE RELATIONSHIP
AND THRESHOLD FOR CNS DEPRESSION
(MONSERCO, 1981)

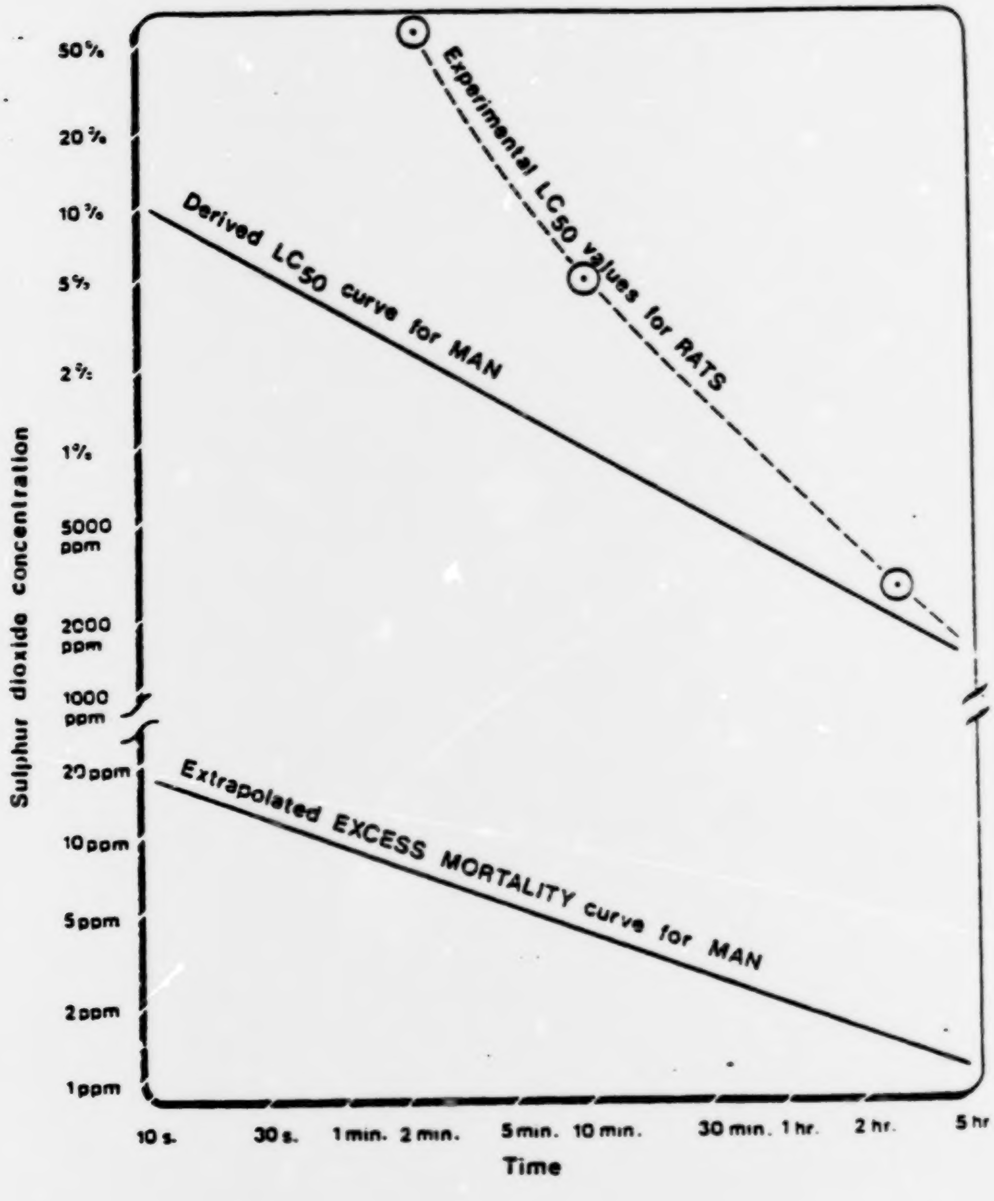
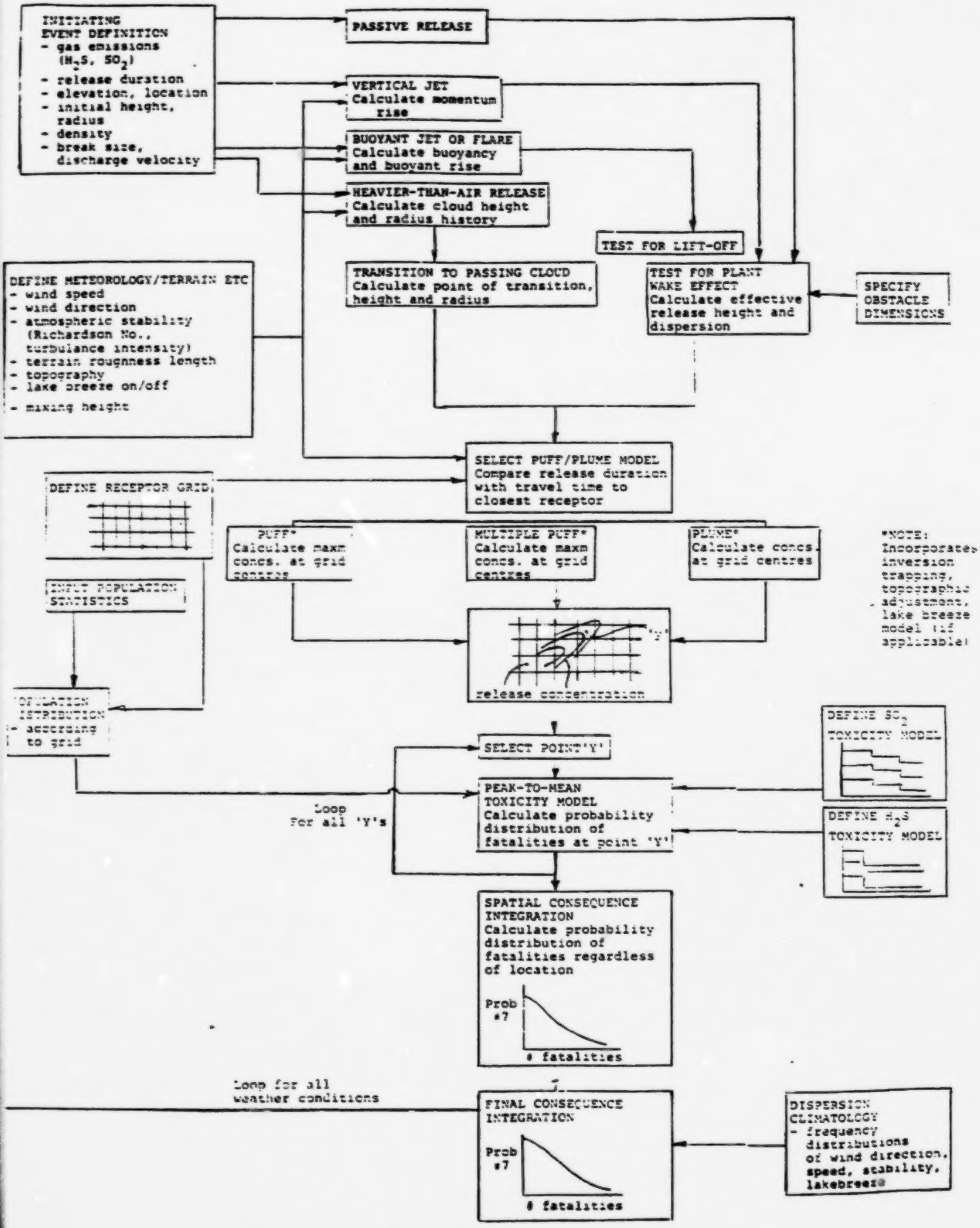


FIGURE 15: HUMAN $SO_2$ DOSE-LETHALITY CURVE AT SHORT EXPOSURE TIMES (ENGELHARDT AND HOLLIDAY, 1981)


INITIATING EVENT DEFINITION
- gas emissions ($H_2S$, $SO_2$)
- release duration
- elevation, location
- initial height, radius
- density
- break size, discharge velocity
PASSIVE RELEASE
VERTICAL JET
Calculate momentum rise
BUOYANT JET OR FLARE
Calculate buoyancy and buoyant rise
HEAVIER-THAN-AIR RELEASE
Calculate cloud height and radius history
TEST FOR LIFT-OFF
TRANSITION TO PASSING CLOUD
Calculate point of transition, height and radius
TEST FOR PLANT WAKE EFFECT
Calculate effective release height and dispersion
SPECIFY OBSTACLE DIMENSIONS
DEFINE METEOROLOGY/TERRAIN ETC
- wind speed
- wind direction
- atmospheric stability (Richardson No., turbulance intensity)
- terrain roughness length
- topography
- lake breeze on/off
- mixing height
SELECT PUFF/PLUME MODEL
Compare release duration with travel time to closest receptor
DEFINE RECEPTOR GRID
PUFF*
Calculate maxm concs. at grid centres
MULTIPLE PUFF*
Calculate maxm concs. at grid centres
PLUME*
Calculate concs. at grid centres
*NOTE: Incorporates inversion trapping, topographic adjustment, lake breeze model (if applicable)
INPUT POPULATION STATISTICS
'Y'
release concentration
OPULATION ISTRIBUTION
- according to grid
DEFINE $SO_2$ TOXICITY MODEL
SELECT POINT 'Y'
PEAK-TO-MEAN TOXICITY MODEL
Calculate probability distribution of fatalities at point 'Y'
DEFINE $H_2S$ TOXICITY MODEL
Loop For all 'Y's
SPATIAL CONSEQUENCE INTEGRATION
Calculate probability distribution of fatalities regardless of location
Prob #?
# fatalities
Loop for all weather conditions
FINAL CONSEQUENCE INTEGRATION
Prob #?
# fatalities
DISPERSION CLIMATOLOGY
- frequency distributions of wind direction, speed, stability, lakebreeze

Number/
Numéro

2

Atomic Energy Control Board
Commission de contrôle de l'énergie atomique

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INFO-0102-2

# PROBABILISTIC CONSEQUENCE ASSESSMENT OF HYDROGEN SULPHIDE RELEASES FROM A HEAVY WATER PLANT - GASPROB CODE DOCUMENTATION

A research report prepared for the
Atomic Energy Control Board by

Monserco Limited
Mississauga, Ontario

June 1983

**RESEARCH REPORT**

# PROBABILISTIC CONSEQUENCE ASSESSMENT OF HYDROGEN SULPHIDE RELEASES FROM A HEAVY WATER PLANT - GASPROB CODE DOCUMENTATION

## ABSTRACT

This report is the second in a series concerned with the evaluation of the consequences to the public of an accidental release of hydrogen sulphide ($H_2S$) to the atmosphere following a pipe or pressure envelope failure, or some other process upset, at a heavy water plant. It consists of documentation of the code GASPROB, which has been developed to provide consequence probabilities for a range of postulated releases. The code includes mathematical simulations of initial gas behaviour upon release to the atmosphere, such as gravitational settling of a cold release and the rise of jets and flares, subsequent atmospheric dispersion under a range of weather conditions, and the toxic effects on the exposed population. The code makes use of the site-specific dispersion climatology, topography and population distribution, as well as the probabilistic lethal dose data for the released gas. Output for a given postulated release can be provided in terms of the concentration of the gas at ground level around the point of release, projected numbers of fatalities within specified areas and the projected total fatalities regardless of location.

This report includes a general description of GASPROB, and specifics of the code structure, the function of each subroutine, input and output data, and the permanent data files established. Three appendices to the report contain a complete code listing, detailed subroutine descriptions and a sample output.

## RÉSUMÉ

Le présent rapport est le deuxième d'une série qui traite de l'évaluation des conséquences pour le public du rejet accidentel d'hydrogène sulfuré ($H_2S$) dans l'atmosphère, à la suite de la défaillance d'une conduite ou d'une enveloppe de pression, ou à la suite de quelque autre perturbation du procédé, dans une usine d'eau lourde. Il fait état de l'utilisation du code GASPROB qui a été mis au point pour fournir des données sur la probabilité des conséquences de plusieurs scénarios de rejet. Le code comprend des simulations mathématiques du comportement initial du gaz au moment du rejet dans l'atmosphère, comme la stabilisation gravitationnelle d'un rejet froid ou l'apparition de jets et de flammes, suivie de la dispersion ultérieure dans l'atmosphère d'après diverses conditions météorologiques; le code touche également aux effets toxiques sur la population exposée. Il fait appel, en outre, aux conditions climatologiques de dispersion d'un site particulier, à la topographie et à la répartition de la population, ainsi qu'aux données probabilistes relatives à la dose létale du gaz rejeté. On peut obtenir ainsi, pour chaque scénario de rejet, des résultats sur la concentration du gaz au sol autour du point de rejet, sur le nombre de mortalités projeté dans certaines zones délimitées et sur le nombre de mortalités projeté sans égard au lieu.

Le rapport donne également une description générale du code GASPROB et des détails sur la structure du code, la fonction de chaque sous-programme, des données d'entrée et des résultats, de même que des dossiers permanents de données. Les trois annexes traitent respectivement d'un listage complet du code, une description détaillée des sous-programmes et un échantillon de résultats.

## DISCLAIMER

The Atomic Energy Control Board is not responsible for the accuracy of the statements made or opinions expressed in this publication and neither the Board nor the author assumes liability with respect to any damage or loss incurred as a result of the use made of the information contained in this publication.

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C.2 - TERRAIN.DAT
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## 1. INTRODUCTION

This report is concerned with the evaluation of the consequences of an accidental release of hydrogen sulphide ($H_2S$) gas to the atmosphere following a pipe or pressure envelope failure, or some other process upset, at a heavy water plant. An earlier report (Monserco, 1983) discussed in depth the nature of the problem to be analyzed and made recommendations for the implementation of a computer model. The present report documents the code, GASPROB, which has been written in accordance with those recommendations. As well, certain meteorological data and population statistics have been obtained for the area of the Bruce heavy water plant (HWP) for input to the model and these are also documented.

Test runs of GASPROB have been executed as part of the development work and, where possible, verification of model components has been carried out by comparison with manual calculations and examination of the output under well-defined conditions. A sample output from the code is given in this report. However, further sensitivity testing of the model and the derivation of consequence assessments for a number of postulated releases is planned for the second phase of this work.

Section 2 of the report contains a description of GASPROB, including the methodological frame-work and the results obtainable. Section 3 describes the overall structure of the code, the individual subroutines, and input and output files (further details of each subroutine, a sample run and code listing are given in appendices). Section 4 documents the permanent data files established for the Bruce HWP area, i.e., population data within a 65 km radius of the plant and the wind and atmospheric stability frequences for the area. The $H_2S$ toxicity data file is also described.

## 2. GENERAL DESCRIPTION

### 2.1 Methodology

Detailed consideration of the elements of the consequence assessment has been given in the previous report in this series (Monserco, 1983). However, the overall methodology followed by GASPROB is repeated below.

GASPROB allows the determination, in probablistic terms, of the consequence of a given release of $H_2S$ from a heavy water plant. It assumes that the specified release, or initiating event, has occurred, and thus falls short of being a full risk assessment. The fundamental relationship simulated by the code can be summarized by Figure 1 and the following equation.

$$P\ (R_n) = \sum_{i,j,k} P\ (C_{i,j,k...} = n) \times P_{i,j,k} \qquad (1)$$

where $P(R_n)$ is the probability that the consequence is n casualties, $P\ (C_{i,j,k...} = n)$ is the probability of n casualties under weather conditions i,j,k... and $P_{i,j,k}$ is the probability of weather conditions i,j,k. In eqn. (1), $P\ (C_{i,j,k...} = n)$ incorporates the effect of atmospheric dispersion of the gas (route to receptor), population density and the number of casualties per unit population exposed (receptor response), integrated over the total area of influence of the release.

Thus, for a given initiating event, the consequence is evaluated in terms of a probability distribution of the number of casualties and is calculated from the probability distribution of casualties under each set of weather conditions and the probability of the weather conditions occurring.

There would be a large number of interacting phenomena and variables contributing to the consequence of any given release, e.g., buoyant rise or gravitational slumping of the gas immediately upon release, the degree of atmospheric dispersion between the point of release and the receptor, the toxicity of the gas at the concentrations and over the exposure times expected downwind, and population density. The overall synthesis of these different factors of the GASPROB model is illustrated in Figure 2, and the individual elements are summarized below.

### 2.2 Initiating Events-Input to GASPROB

GASPROB has been designed to simulate nine categories of initiating events specifically related to heavy water plants:

a) catastrophic failure of an enriching unit tower,
b) non-burning or burning release from pipe breaks of 0.15 - 1.3 m (6-52 in) diameter,
c) non-burning release from a 0.6m (24 in) manhole in enriching unit tower,
d) non-burning release from pipe breaks of 0.05 - 0.1 m (2 - 4 in) diameter,
e) catastrophic failure of $H_2S$ storage tank,
f) failure of storage tank manhole,
g) failure of liquid line or bottom nozzle in $H_2S$ storage area,
h) catastrophic tank car failure,
i) burning or non-burning dump to flare.

A number of such releases can be assumed to be occurring simultaneously in the model.

Depending on the time history of the gas blowdown, GASPROB treats the release as a continuous "plume", an instantaneous "puff" or a series of puffs representing a time varying emission. The release rates or amounts must be specified by the user, together with their respective physical locations in the horizontal and vertical (details of user options and input data requirements are given in Section 3 and Appendix C of this report).

### 2.3 Route to Receptor

This portion of the code is concerned with the initial gas behaviour and the subsequent transport and dispersion. The initial gas behaviour, in this context, means the density and/or momentum dominated phases immediately following release to atmosphere. GASPROB has the capability to predict, at the user's option, the following effects:

a) momentum rise of a vertical jet of gas discharged from a pipe,
b) buoyant plume rise due to a burning release, or flare, of $H_2S$,
c) lift-off of a ground level buoyant release,
d) gravitational behaviour of a dense gas cloud,
e) transition of a dense cloud to passive cloud behaviour,
f) plant aerodynamic wake effects.

The program modules which simulate these effects provide, as output, the effective release height and, where applicable, initial cloud dimensions and position at the beginning of the passive transport and dispersion phase. Gaussian plume and puff dispersion models are then used to represent, respectively, continuous and instantaneous or short-term releases. An option is available to account for trapping beneath an elevated inversion.

Since GASPROB is intended for immediate application to the Bruce HWP, the code incorporates an optional lakebreeze dispersion model in which releases made into a relatively stable air layer aloft are fumigated to ground level further inland. A terrain adjustment option is also included to simulate the effect of topography on ground level concentrations.

For a given initiating event and set of meteorological conditions (wind speed, direction, atmospheric stability, trapping inversion, lakebreeze), the code can provide maximum gas concentrations at downwind receptors in the path of the release. In the case of a transient release, the maximum concentration experienced can be reduced if the receptor is inside a building. This effect can be included at the option of the user. Concentrations are output at the element and sub-element centers of gravity, as defined in the terrain input file (see Section 4 below).

## 2.4 Receptor Response

The receptor response portion of the code is built around the statistical "peak-to-mean" model developed earlier for the AECB by Monserco (1981). This model predicts the probability of short-term lethal concentration peaks of ($H_2S$) (or $SO_2$, if a lethal dose relationship for the gas is available). In GASPROB it is used to derive the overall probability of all possible lethal concentration - exposure time combinations at a given receptor.

To perform the full consequence assessment, the lethal dose relationship should be input in step function form for several probability levels, i.e. $LC_{50}$, $LC_{90}$ functions etc. This results in a probability distribution of the number of fatalities at the receptor, or grid element, in question.

GASPROB then adds up the results for all grid elements and produces a probability distribution for the whole area under study. A further addition of consequence probabilities is performed for the range of possible weather conditions simulated, each condition being weighted according to its relative frequency of occurrence. The latter feature of GASPROB involves the use of site-specific climatological data in statistical form which must be input to the program.

### 2.5 Code Specifications

The GASPROB code is presently written in ASCII FORTRAN on the Monserco computer facility, comprised of a Digital Equipment VAX 11/750 and support pheripherals. There are approximately 3400 lines of coding divided into 52 subroutines. Double precision variables (sixty-four bit words) have been used to represent all values, with the exception of the dense gas segment. The program requires an in core storage of 129 k Bytes and a total in core user allocation of approximately 374 k Bytes. Extensive use of the Monserco library routines have been made for programming efficiency. These routines perform many of the support functions, including terrain manipulation, plotting routines, sorting functions and mathematical packages for solution of differential equations, derivation of roots and curve fitting.

## 3. MODEL STRUCTURE

The code GASPROB consists of 52 subroutines which perform the various functions of data input, terrain definition, dispersion calculations, and consequence analysis. The structure of the code is relatively straightforward, in that subroutine MAIN functions as the mainline which calls the required routines applicable to the present run. The code incorporates part of the program DENZ (Fryer and Kaiser, 1979), the heavier than air release option, a modified version of the risk consequence program $H_2S$ RISK (Monserco, 1981) to determine probabilities of exceeding the lethal dose rates, as well as several library routines. Descriptions of the codes $H_2S$ RISK and DENZ are adequately documented in the references and have not been repeated here.

## 3.1 GASPROB Subroutine Structure

Figure 3 contains a flowchart of the various calls of the mainline routine MAIN. Data input is through routines INPUTT, INPUTR, INPUTP, INPUTC. Input data is prepared in the permanent data files TERRAIN.DAT and PROBCON.DAT, and from the run file (temporary) GASPROB.DAT. The terrain data file contains all details specific to the site of interest including grid element positions, elevations, and population data. All toxicity data is placed in the PROBCON.DAT file. The library routine DIVIS sorts the terrain input into discreet area elements whose size is controlled by user specification. The areas of the trapezoidal grid elements are calculated for population density calculations and CG is called for calculation of the centre of the element, which will be used to represent that location in the dispersion calculation. Debugging options may be specified which allow only the site data to be read in and a listing made of the terrain data, or a high resolution plot made through TERRPLOT. Appendix C contains a sample run of GASPROB.

Subroutine INPUTR and INPUTC reads all information applicable to the present run from the GASPROB.DAT data file. INPUTP stores all toxicity data in the form of up to ten lethal dose curves ($LC_{50}$, $LC_{90}$, etc.).

Routine CONVERT is used to establish the relative position of each grid point from the source origin for use in the dispersion calculations.

Subroutine FLARE and VJET calculate any increase in the effective height of release due to buoyancy and a vertical jet respectively. The effective release height can also be adjusted for terrain elevation differences by TERR. If a heavier than air release is specified, the routine HEAVY calculates the size of the effective cloud at the time when it becomes passive. This routine has been modified from the DENZ code. A lakebreeze effect can be considered through a call to routine LAKE. Both puff and plume models may be considered for passive releases through subroutines PLUME or PUFF. Any trapping effect is included in routine TRAP which also calculates the effect of height of release. The calculation of the dispersion coefficients is made through routine SIG, which allows three different options and two modifications due to gravity effects or building wake effects in the near field. After the calculation of the maximum concentration has been made (output of routine LAKE, PLUME, or PUFF) the next emission source in the particular accident scenario is considered. Concentrations from up to ten sources can be accumulated. When all sources have been considered for a given weather condition, the routine LINK is called to calculate the consequence of the concentration of toxic gas at each terrain element. LINK is a conditioning routine which calls the modified $H_2S$ RISK routine RISK. The consequence of the release is then summed over the entire map to obtain a total effect for the weather case. Routine SUMMAT stores the effect of each weather case and accumulates the overall effect for all cases, weighted by the probability of that meteorological case occurring.

The output of the code consists of a listing of the input data (for run documentation purposes), the gas concentration and number of casualties at each terrain grid point, and the total number of casualties over the entire study area. Casualty figures are given for four probability levels.

## 3.2 Available Options

Several options are available in GASPROB. The routine INPUTT allows input of the population data in the form of population densities or numbers of people. The data file GASPROB.DAT allows input of the variable IRUNCODE such that if IRUNCODE = 1 a full consequence analysis is made and if IRUNCODE = 2 only the dispersion calculations are made.

All other modelling options are input through the eleven variable array IOPTION as follows.

File GASPROB.DAT

| | | |
|---|---|---|
| Record 2 | (IOPTION (I), I = 1,11) | |
| | -IOPTION (1) | Plume Model=1, Puff Model.NE.1<br>Indoor/outdoor peak to mean effect of puff model = 3 |
| | -IOPTION (2) | Sigma y,z options 1,2, or 3 |
| | -IOPTION (3) | Weather class (1=A, 2=B,...6=F) |
| | -IOPTION (4) | Terrain Roughness (1,2,...6) |
| | -IOPTION (5) | Gravity effect option (1=include) |
| | -IOPTION (6) | Building effect option (1=include) |
| | -IOPTION (7) | Terrain modification (1=include) |
| | -IOPTION (8) | Trapping option (1=include) |
| | -IOPTION (9) | Lake breeze effect (1=include) |

-IOPTION (10) Debug Diagnostic Switch
= 1 Additional listing included
= 2 Terrain plot included

-IOPTION (11) Type of Release
= 1 Passive Release
= 2 Vertical Jet
= 3 Flare
= 4 Heavier than air

## 3.3 Constraints of Program

The code can accommodate up to a maximum of 1000 weather cases within each run. Concentrations from a maximum of 100 simultaneous emission sources can be accumulated to describe a postulated accident. The sources may be at different heights and released from different locations. If the PUFF model is used, up to 100 puffs can be used to described a time varying emission, or blowdown.

The terrain data is input by specifying up to 1000 terrain elements. These input elements may be internally subdivided to obtain greater definition, up to a maximum number of 100 sub-elements.

Up to ten lethal dose concentration curves can be input with up to ten co-ordinates used to specify each curve.

All units used in the program are consistant with the metre-kilogram-secs system. Terrain co-ordinates are in kilometres.

## 3.4 Sample Run

Contained in Appendix C3 is a sample of the input and output of a run of GASPROB. Figure 4 shows a computer plot of the Bruce County area which was used in the example. The meteorological conditions are a westerly wind of

5 m/sec, and stability category 'D'. The source is a release of 335 kg/sec of $H_2S$ from about the centre of the Bruce Heavy Water Plant. It is assumed to be released at ground level as a passive plume. The dispersion coefficients were calculated according to the Smith-Hosker model with a terrain roughness length assumed to be 100 mm. The summary of input data in the list file GASPROB.LIS contains other data specifications, such as lid height, values for $\sigma_\theta$, $\sigma_\phi$, but these were not used in this run.

In the output, the location numbers used correspond to the grid location numbers shown on the site plot of Figure 4. As can be seen from the listing 'cumulative concentration for case no. 1', a concentration peak of 50.77 mg/m³ was found at location 146. The output titled 'Debugging Dump of PK's'contains the output of the RISK routine. For example, at location 146 the probability of exceeding the one percent lethal dose concentration is $0.382 \times 10^{-6}$.

The subsequent table shows the affected population at each location for each of four probability levels. The final summary shows the cumulative consequence of the release over the complete area of study.

## 4. PERMANENT DATA FILES

In the course of the development work for GASPROB, terrain and population data specific to the area of the Bruce HWP, within a radius of 65 km of the plant, have been gathered. These have been assembled as a permanent input data file, TERRAIN.DAT, listed in Appendix C.1. The file contains the idealized co-ordinates of the population enumeration areas, the population within each area and the average terrain elevation (above Lake Huron) of each area. The enumeration areas become the basic grid elements of the model, identified by a number (1 to 256). TERRAIN.DAT also specifies the node numbers at the corners of the elements. Appendix C.0 gives further details of the file structure.

PROBCON.DAT contains the lethal dose (time-concentration) relationship for $H_2S$ developed in an earlier study by Monserco (1981). This is in the form of a step function. For the purposes of the sample runs of GASPROB, this relationship is assumed to correspond to the $LC_1$ curve, i.e. fatalities are 1% of the population. PROBCON.DAT also contains a simulated $LC_{50}$ curve.

Relative frequencies of wind speed, wind direction and atmospheric stability class (A-F) have been obtained from Environment Canada, based on ten years of hourly data collected at Wiarton, Ontario, the closest first order weather station to Bruce HWP. A sample of the data (annual relative frequencies of wind speed and direction for stability class D) is given in Table 1. The frequency analyses are available on an annual and monthly basis.

# REFERENCES

1. Fryer, L.S. & G.D. Kaiser (1979). DENZ - A computer program for the calculation of the dispersion of dense toxic or explosive gases in the atmosphere. UKAEA Report SRD R152, July 1979.

2. MONSERCO (1981): The influence of short-term concentration peaks on exposure risks in the vicinity of an episodic release of hydrogen sulphide. A research report prepared for the Atomic Energy Control Board, AECB Report INFO-0032, May 15, 1981.

3. MONSERCO (1983): Probabilistic consequence assessment of hydrogen sulphide releases from a heavy water plant-scope determination. A research report prepared for the Atomic Energy Control Board, Jan. 20, 1983.

# TABLE 1

ANNUAL RELATIVE FREQUENCY DISTRIBUTION STATION = WIARTON 1972-81

| DIRECTION | SPEED(KTS) 0 - 3 | 4 - 6 | 7 - 10 | 11 - 16 | 17 - 21 | GREATER THAN 21 | TOTAL |
|---|---|---|---|---|---|---|---|
| N | 0.006011 | 0.008268 | 0.010370 | 0.008535 | 0.000662 | 0.000093 | 0.033939 |
| NNE | 0.004179 | 0.006097 | 0.008361 | 0.007107 | 0.000941 | 0.000163 | 0.026847 |
| NE | 0.003041 | 0.004796 | 0.007571 | 0.008802 | 0.001603 | 0.000255 | 0.026069 |
| ENE | 0.002659 | 0.004064 | 0.007165 | 0.007037 | 0.001208 | 0.000163 | 0.022296 |
| E | 0.004247 | 0.005888 | 0.011206 | 0.009220 | 0.001812 | 0.000232 | 0.032605 |
| ESE | 0.003431 | 0.004575 | 0.007246 | 0.004854 | 0.001022 | 0.000058 | 0.021186 |
| SE | 0.003409 | 0.004076 | 0.005911 | 0.003658 | 0.000465 | 0.000023 | 0.017541 |
| SSE | 0.003520 | 0.004331 | 0.007931 | 0.005597 | 0.001184 | 0.000232 | 0.022796 |
| S | 0.005849 | 0.008895 | 0.024084 | 0.029774 | 0.006584 | 0.001579 | 0.076766 |
| SSW | 0.002686 | 0.004192 | 0.011020 | 0.017802 | 0.005121 | 0.001428 | 0.042250 |
| SW | 0.003281 | 0.005063 | 0.009290 | 0.019997 | 0.007420 | 0.002764 | 0.047815 |
| WSW | 0.004710 | 0.006340 | 0.012774 | 0.023527 | 0.006317 | 0.002671 | 0.056340 |
| W | 0.005984 | 0.009000 | 0.016931 | 0.024909 | 0.004657 | 0.001452 | 0.062931 |
| WNW | 0.003574 | 0.005377 | 0.011206 | 0.016710 | 0.003461 | 0.001161 | 0.041489 |
| NW | 0.004175 | 0.006143 | 0.010602 | 0.010881 | 0.001997 | 0.000383 | 0.034182 |
| NNW | 0.004170 | 0.005725 | 0.007792 | 0.005992 | 0.000732 | 0.000046 | 0.024457 |
| TOTAL | 0.064925 | 0.092830 | 0.169461 | 0.204403 | 0.045184 | 0.012704 | |

RELATIVE FREQUENCY OF OCCURRENCE OF D STABILITY = 0.595509

RELATIVE FREQUENCY OF CALMS DISTRIBUTED ABOVE WITH D STABILITY = 0.027789

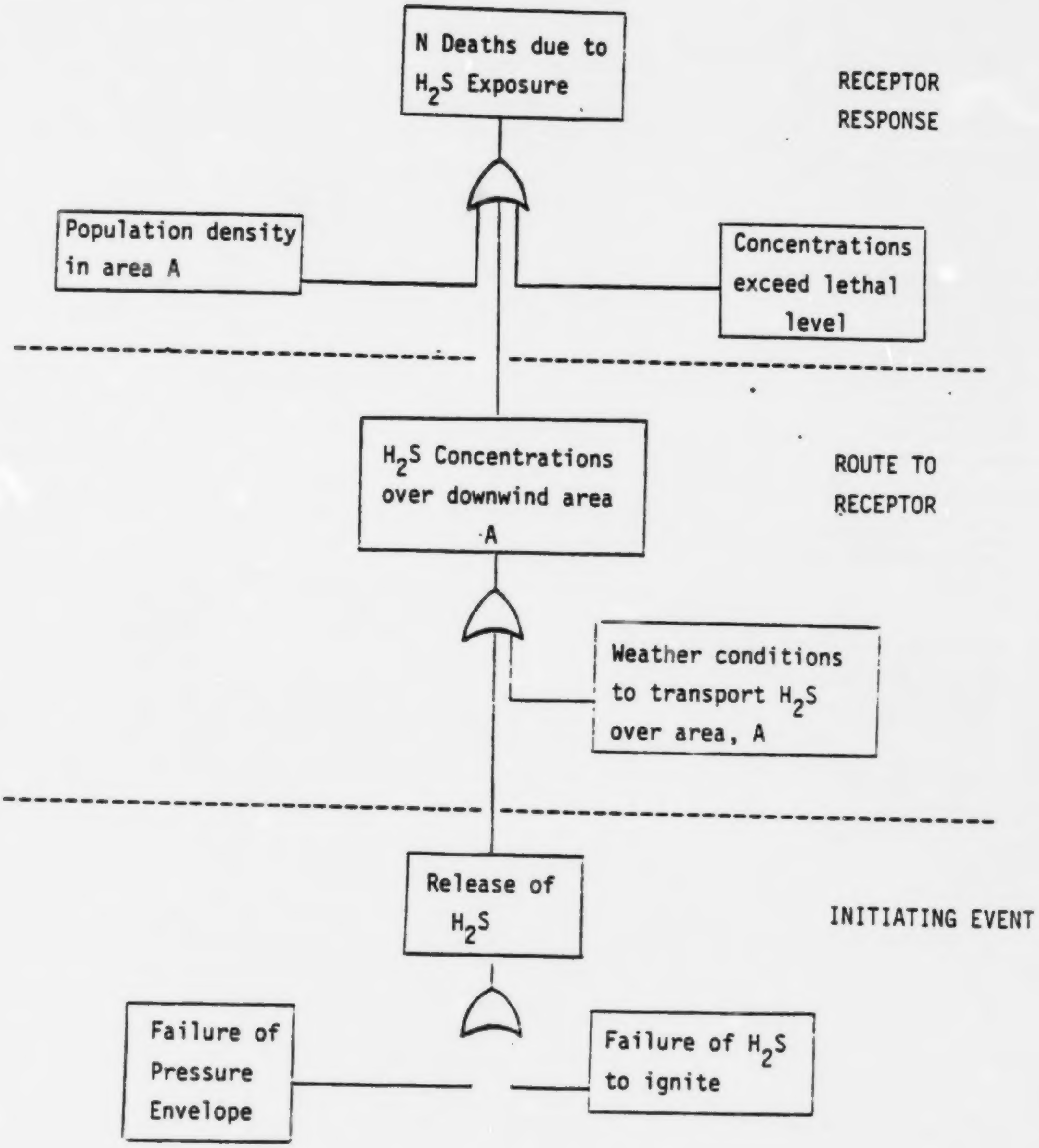
N Deaths due to $H_2S$ Exposure
RECEPTOR RESPONSE
Population density in area A
Concentrations exceed lethal level
$H_2S$ Concentrations over downwind area A
ROUTE TO RECEPTOR
Weather conditions to transport $H_2S$ over area, A
Release of $H_2S$
INITIATING EVENT
Failure of Pressure Envelope
Failure of $H_2S$ to ignite

FIGURE 1

SIMPLIFIED FAULT TREE FOR FATALITIES DUE TO ATMOSPHERIC RELEASE OF $H_2S$

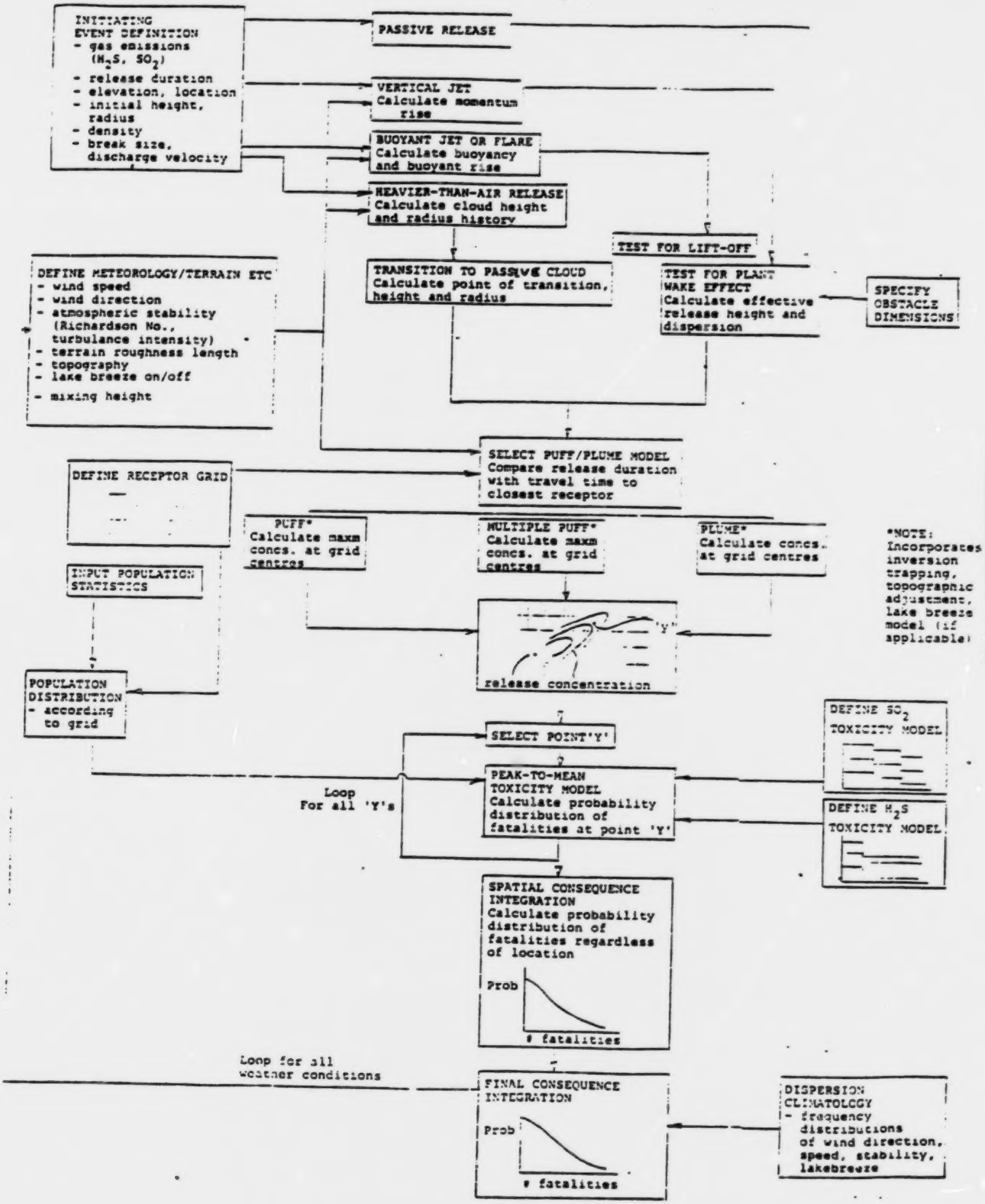
INITIATING EVENT DEFINITION
- gas emissions ($H_2S$, $SO_2$)
- release duration
- elevation, location
- initial height, radius
- density
- break size, discharge velocity
PASSIVE RELEASE
VERTICAL JET
Calculate momentum rise
BUOYANT JET OR FLARE
Calculate buoyancy and buoyant rise
HEAVIER-THAN-AIR RELEASE
Calculate cloud height and radius history
TEST FOR LIFT-OFF
DEFINE METEOROLOGY/TERRAIN ETC
- wind speed
- wind direction
- atmospheric stability (Richardson No., turbulance intensity)
- terrain roughness length
- topography
- lake breeze on/off
- mixing height
TRANSITION TO PASSIVE CLOUD
Calculate point of transition, height and radius
TEST FOR PLANT WAKE EFFECT
Calculate effective release height and dispersion
SPECIFY OBSTACLE DIMENSIONS
SELECT PUFF/PLUME MODEL
Compare release duration with travel time to closest receptor
DEFINE RECEPTOR GRID
PUFF*
Calculate maxm concs. at grid centres
MULTIPLE PUFF*
Calculate maxm concs. at grid centres
PLUME*
Calculate concs. at grid centres
*NOTE: Incorporates inversion trapping, topographic adjustment, lake breeze model (if applicable)
INPUT POPULATION STATISTICS
'Y'
release concentration
POPULATION DISTRIBUTION
- according to grid
SELECT POINT 'Y'
DEFINE $SO_2$ TOXICITY MODEL
PEAK-TO-MEAN TOXICITY MODEL
Calculate probability distribution of fatalities at point 'Y'
Loop For all 'Y's
DEFINE $H_2S$ TOXICITY MODEL
SPATIAL CONSEQUENCE INTEGRATION
Calculate probability distribution of fatalities regardless of location
Prob
# fatalities
Loop for all weather conditions
FINAL CONSEQUENCE INTEGRATION
Prob
# fatalities
DISPERSION CLIMATOLOGY
- frequency distributions of wind direction, speed, stability, lakebreeze

FIGURE 2
FLOW CHART ILLUSTRATING GASPROB METHODOLOGY

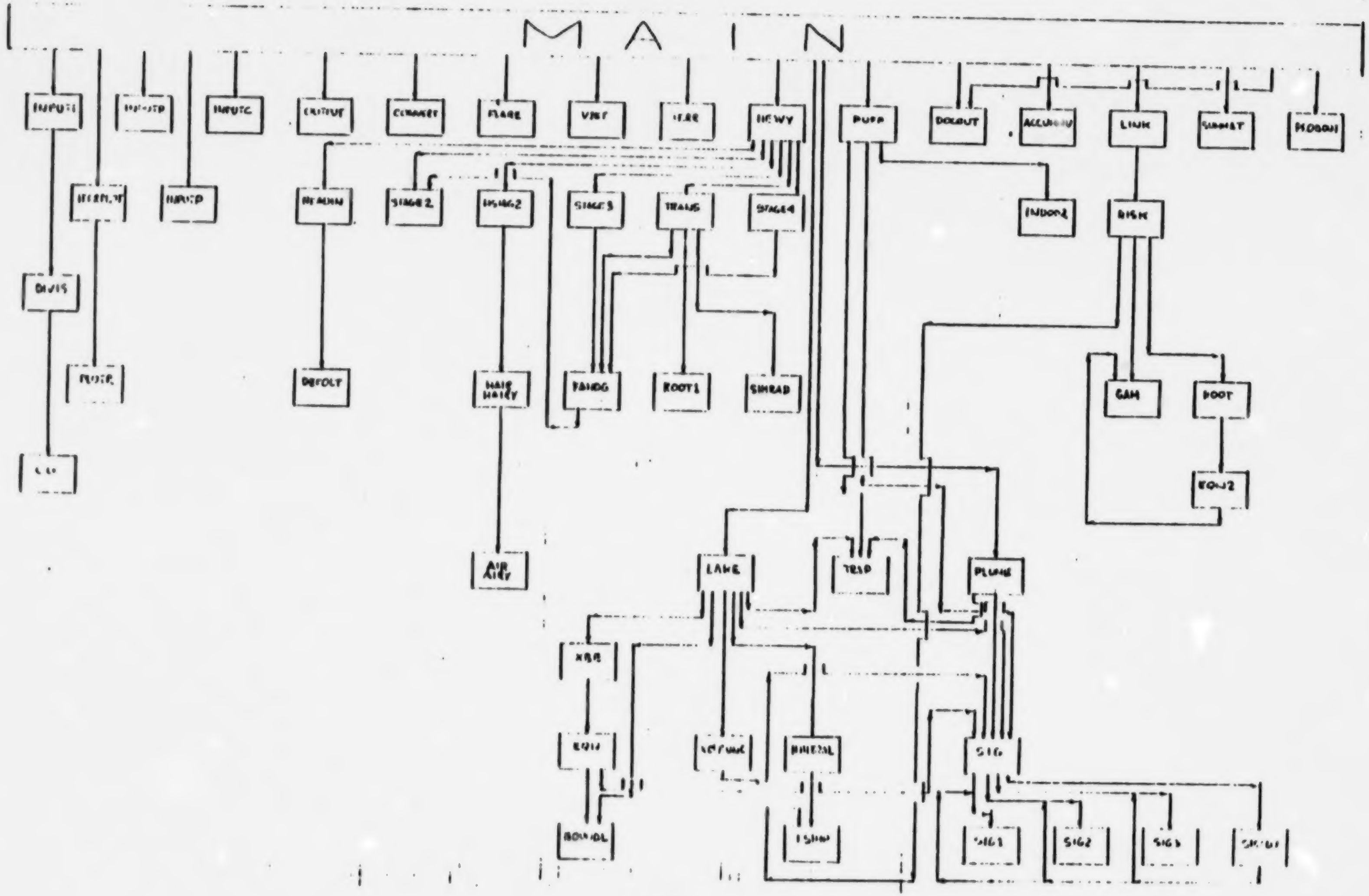
MAIN
INPUTC
FLARE
HEWY
PUFF
LINK
RISK
GAM
ROOT
EQN2
DIVIS
DEFOLT
STAGE2
STAGE3
TRANS
STAGE4
ROOT1
SIMRAD
LAKE
PLUME
SIG
SIG1
SIG2
SIG3

FIGURE 3

GASPROB Subroutine Flowchart

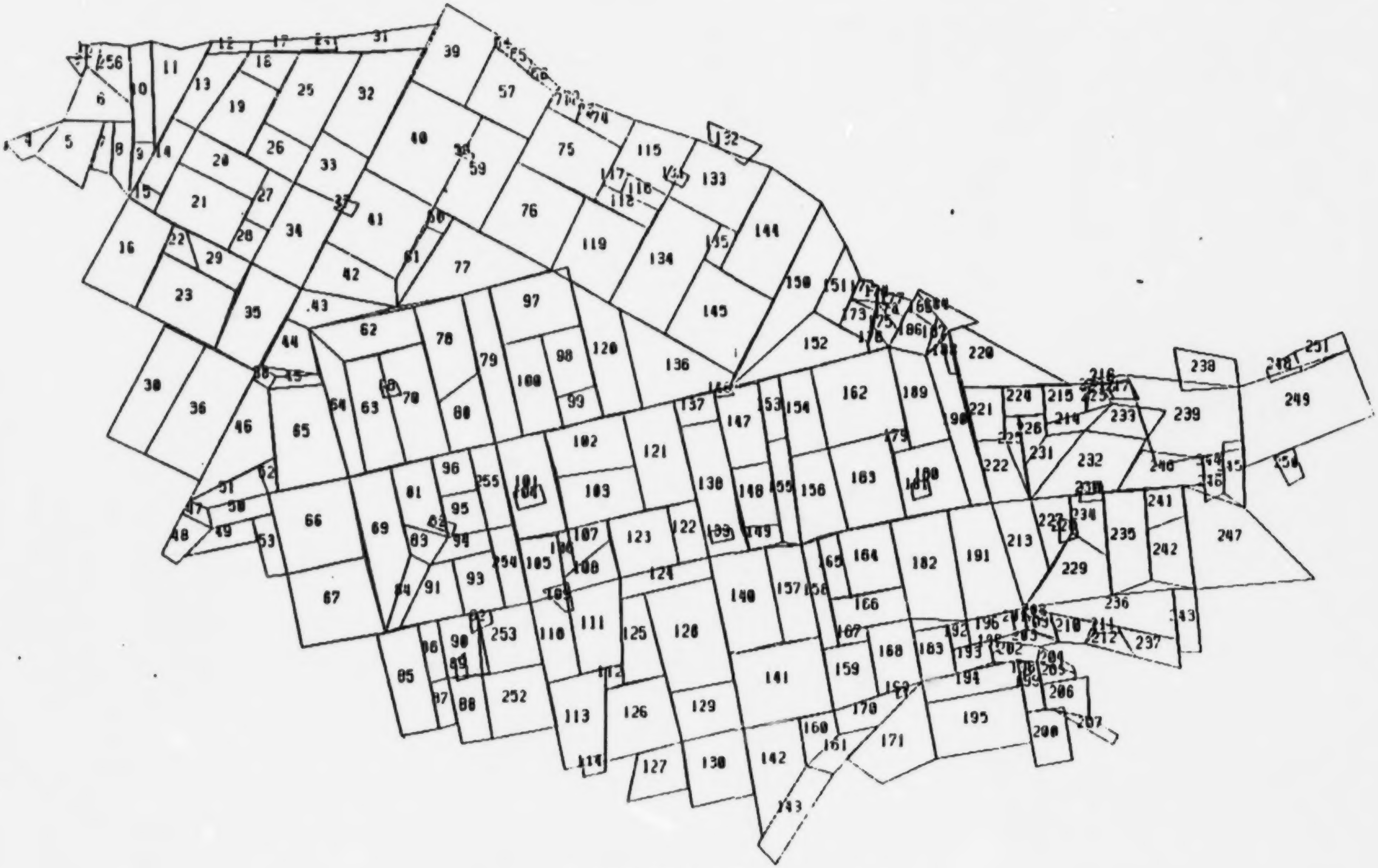

FIGURE 4

COMPUTER GENERATED MAP OF BRUCE HWP AREA SHOWING ENUMERATION AREAS

# APPENDIX A

## GASPROB LISTING

```
          C
          C        MAINLINE
          C
0001               IMPLICIT REAL*8 (A-H,O-Z)
0002               DIMENSION TRANSFER(5)
0003               INCLUDE 'OPTIONS.CMN'
        * C
        * C        OPTIONS CONTAIN ALL OPTIONS REQUIRED FOR EXECUTION
        * C
0004    *          COMMON /OPTIONS/ IOPTION(11),IRUNCODE
        * C         IOPTION IS DEFINED AS FOLLOWS :
        * C                     IOPTION(1)  : PLUME MODEL=1; PUFF .NE. 1; IN/OUTDOOR=3
        * C                     IOPTION(2)  : SIGMA Y,Z OPTIONS 1,2,OR 3
        * C                     IOPTION(3)  : WEATHER CLASS (1=A,2=B,...6=F)
        * C                     IOPTION(4)  : TERRAIN ROUGHNESS(1,2,...6)
        * C                     IOPTION(5)  : GRAVITY EFFECT OPTION (1=INCLUDE)
        * C                     IOPTION(6)  : BUILDING EFFECT OPTION (1=INCLUDE)
        * C                     IOPTION(7)  : TERRAIN MODIFICATION (1=INCLUDE)
        * C                     IOPTION(8)  : TRAPPING OPTION (1=INCLUDE)
        * C                     IOPTION(9)  : LAKE BREEZE EFFECT (1=INCLUDE)
        * C                     IOPTION(10) : DEBUGGING SWITCH 1= ADDITIONAL OUTPUT
        * C                                                    2= TERRAIN PLOT PRODUCED
        * C                     IOPTION(11) : RELEASE TYPE 1=PASSIVE
        * C                                                2=VERTICAL JET
        * C                                                3=FLARE
        * C                                                4=HEAVIER THAN AIR
0005               INCLUDE 'ATMOS.CMN'
        * C
        * C        ATMOS CONTAINS ALL PERTINENT DATA FOR CONCENTRATION
        * C        CALCULATIONS AND DETERMINATION OF SIGMA'S
        * C
0006    *          COMMON /ATMOS/ GRATE(100),USPEED,HEIGHT(100),SIGY,
        *         ZSIGZ,SIGTHETA,SIGPHI,XT,RT,HT,C,AO,XLS(100),
        *         ZELEVSOUR(100),XLID,WDIR,SX(100),SY(100),
        *         ZILAKE,IWCLASS2,NSOURCE
0007               INCLUDE 'RELTYPE.CMN'
0008    *          COMMON /RELTYPE/ DISCH(100),WO,SO2FLOW(100),DTHDZ,ALPHA,
        *         ZU10,CFLARE,AMTEMP
0009               INCLUDE 'PUFF.CMN'
        * C
        * C         PUFF CONTAINS THE PUFF MODEL SPECIFIC SOURCE ARRAYS
        * C
0010    *          COMMON /PUFF/ PUFFT(100,100),PUFFQ(100,100),TAUB,TAU
0011               OPEN(UNIT=1,NAME='TI: ',TYPE='OLD')
0012               OPEN(UNIT=2,NAME='GASPROB.DAT',TYPE='OLD')
0013               OPEN(UNIT=3,NAME='GASPROB.LIS',TYPE='NEW')
0014               OPEN(UNIT=4,NAME='TERRAIN.DAT',TYPE='OLD')
0015               OPEN(UNIT=5,NAME='PROBCON.DAT',TYPE='OLD')
0016               OPEN(UNIT=6,NAME='HEAVY.DAT',TYPE='OLD')
          C
          C         CALL INPUTT TO DEFINE TERRAIN
          C
0017               CALL INPUTT
          C
          C         READ IN DATA SPECIFIC TO THIS RUN
          C
0018               CALL INPUTR
```

```
C
C       CALL OUTPUT TO DUMP TERRAIN DATA FOR INPUT VERIFICATION
C
      IF(IOPTION(10).NE.0) CALL OUTPUT
      IF(IOPTION(10).EQ.2) CALL TERRPLOT
C
C       READ IN PROBABILITY CONSEQUENCE DATA
C
      IF(IRUNCODE.NE.2) CALL INPUTP
C
  10  CONTINUE
C
C       READ IN DATA SPECIFIC TO THIS CASE
C
      CALL INPUTC(ICASE)
      IF(ICASE.EQ.0) GO TO 11
      WRITE(1,20) ICASE
  20  FORMAT('+WORKING ON CASE ',I4)
C
C       LOOP THROUGH THE SOURCES
C
      DO 30 ISOURCE=1,NSOURCE
C
C       CALL CONVERT TO CALCULATE X,Y FROM SOURCE & CG'S
C
      CALL CONVERT(ISOURCE)
C
C       ADJUST USPEED TO PHYSICAL STACK HEIGHT
C
      U10=USPEED
      IF(HEIGHT(ISOURCE).LE.10.) GO TO 12
      IF(HEIGHT(ISOURCE).LE.50.) THEN
                           USTAR=USPEED*0.4/LOG(10./Z0)
                           USPEED=USTAR/0.4*LOG(HEIGHT(ISOURCE)/Z0)
                        ELSE
                           USPEED=USPEED*(HEIGHT(ISOURCE)/10.)**ALPHA
                        ENDIF
  12  CONTINUE
C
C       CHECK FOR TYPE OF RELEASE
C
      IF(IOPTION(11).EQ.2) CALL VJET
      IF(IOPTION(11).EQ.3) CALL FLARE
      IF(IOPTION(11).EQ.4) THEN
                       CALL HEAVY(TRANSFER)
                       XT=TRANSFER(1)
                       HT=TRANSFER(2)
                       RT=TRANSFER(3)
                       PUFFQ(ISOURCE,1)=TRANSFER(5)
                       PUFFQ(ISOURCE,2)=0.0
                       PUFFT(ISOURCE,1)=XT/USPEED
                       ENDIF
C
C       CALL TERR TO CHECK FOR RELEASE HEIGHT ADJUSTMENT
C
      CALL TERR(ISOURCE)
C
```

```
      C      CHECK IF LAKEBREEZE OPTION IS TO BE USED
      C
            IF(IOPTION(9).EQ.1) THEN
                          CALL LAKE(ISOURCE)
                      ELSE
                          IF(IOPTION(1).EQ.1) THEN
                                      CALL PLUME(ISOURCE)
                                  ELSE
                                      CALL PUFF(ISOURCE)
                                      ENDIF
                          ENDIF
            CALL ACCUMMU(ISOURCE)
            CALL DOCOUT(ICASE,ISOURCE)
        30  CONTINUE
      C
      C      CALL LINK TO CALCULATE THE PROBABILITIES FROM RISK
      C
            CALL LINK(ICASE)
            GO TO 10
        11  CONTINUE
            CALL SUMMAT
            CALL PROBOUT
            STOP' RUN COMPLETE'
            END
```

```
PROGRAM SECTIONS

    Name                                        Bytes   Attributes

  0 $CODE                                         605   PIC CON REL LCL   SHR    EXE    RD
  1 $PDATA                                         97   PIC CON REL LCL   SHR  NOEXE    RD
  2 $LOCAL                                        304   PIC CON REL LCL NOSHR  NOEXE    RD
  3 OPTIONS                                        48   PIC OVR REL GBL   SHR  NOEXE    RD
  4 ATMOS                                        4908   PIC OVR REL GBL   SHR  NOEXE    RD
  5 RELTYPE                                      1648   PIC OVR REL GBL   SHR  NOEXE    RD
  6 PUFF                                       160016   PIC OVR REL GBL   SHR  NOEXE    RD

ENTRY POINTS

    Address   Type  Name

  0-00000000        MAIN$MAIN

VARIABLES

    Address   Type  Name                  Address   Type  Name                  Address   Ty

  4-00000688  R*8   A0                  5-00000650  R*8   ALPHA               5-00000668  R
  5-00000660  R*8   CFLARE              5-00000648  R*8   DTHDZ               4-00000678  R
  4-00001320  I*4   ILAKE               3-0000002C  I*4   IRUNCODE            2-0000003C  I
  4-00001328  I*4   NSOURCE             4-00000670  R*8   RT                  4-00000660  R
  4-00000648  R*8   SIGY                4-00000650  R*8   SIGZ                6-00027108  R
```

```
                                                        25-May-1983 17:04:
                                                         5-May-1983 17:00:
      C
      C       ROUTINE TO STORE CUMMULATIVE CONCENTRATIONS OF PREVIOUS CASES
      C
              SUBROUTINE ACCUMMU(ISOURCE)
              IMPLICIT REAL*8 (A-H,O-Z)
              INCLUDE 'PARA.CMN'
    * C        COMMON PARA IS THE MAIN PARAMETER BLOCK
    * C        -CGX,CGY ARE THE LOCATIONS OF THE CG OF
    * C         THE AREA BEING REPRESENTED
    * C        -POP IS THE POPULATION REPRESENTED AT THE CG (IN # OF PEOPLE)
    * C        -AREA IS THE AREA OF THE REPRESENTED ELEMENT OF TERRAIN(KM**2)
    * C        -ELEV IS ELEVATION OF AREA
    * C        -H IS THE EFFECTIVE RELEASE HEIGHT
    * C        -XCORD,YCORD ARE THE COMPONENTS FOR THE CONCENTRATION CALC
    * C
    *         COMMON /PARA/ CGX(1000),CGY(1000),AREA(1000),POP(1000)
    *        Z,ELEV(1000),NP,H(1000),CONC(1000),XCORD(1000),YCORD(1000)
              INCLUDE 'ACCUMMUL.CMN'
    * C
    * C        ACCUMMUL CONTAINS THE CUMMULATIVE STORED CONCENTRATIONS
    * C        FOR ALL CASES IN THE PRESENT RUN
    * C
    *         COMMON /ACCUMMUL/ACCUM(1000)
              INCLUDE 'ATMOS.CMN'
    * C
    * C       ATMOS CONTAINS ALL PERTINENT DATA FOR CONCENTRATION
    * C       CALCULATIONS AND DETERMINATION OF SIGMA'S
    * C
    *         COMMON /ATMOS/ GRATE(100),USPEED,HEIGHT(100),SIGY,
    *        ZSIGZ,SIGTHETA,SIGPHI,XT,RT,HT,C,AO,XLS(100),
    *        ZELEVSOUR(100),XLID,WDIR,SX(100),SY(100),
    *        ZILAKE,IWCLASS2,NSOURCE
              DO 10 I=1,NP
              ACCUM(I)=ACCUM(I)+CONC(I)
          10  CONTINUE
              IF(ISOURCE.EQ.NSOURCE) THEN
                          DO 20 I=1,NP
                          CONC(I)=ACCUM(I)
                          ACCUM(I)=0.
          20              CONTINUE
                          ENDIF
              RETURN
              END
```

```
        SUBROUTINE AIRY(Y, D, W, H, T, NN, JJ, MM)
        DIMENSION Y( NN), D(NN), W(5000), H(1), T(1), JJ(1)
         LOGICAL L
        DIMENSION CHA(3), CHF(4), CHM(4)
        DATA CHA /  3. 66667, 2. 0, 1. 0  /
        DATA CHF /  0. 17, 0. 25, 1. 0, 8. 625  /
        DATA CHM /  0. 96875, 1. 015625, 1. 0625, 1. 3125  /
        DATA CH1/0. 48/
        DATA CH2/32. 0E6 /
C --- -----------------------------    VERSION OF 30MAR69
        JJ(1)=1
        M=MAXO(MM, 5)
        M=MINO(M, 18)
        CL=0. 5**M
        N=NN
        N4=4*N
        RETURN
        ENTRY AIR
        J=JJ(1)
        IF (J) 2, 5, 1
   1    IF (J-5) 4, 70, 2
   2    J=1
        GO TO 9
   4    GO TO (10, 20, 30, 40), J
C --- -----------------------------    J=0 ENTRY
   5    DO 7 I=1, N
   7    Y(I)=W(I)
        DH=DH/32. 0
        GO TO 13
C --- -----------------------------    J=1 ENTRY
  10    DH=0. 0
C --- -----------------------------    J=3 ENTRY
  30    TR=T(1)
        HR=H(1)
        TE=TR+HR
        HX=HR
        ZT=1. 0
        IF (HR) 2, 31, 32
  32    IF (DH) 11, 11, 280
  11    DO 12 I=1, N
  12    W(I)=Y(I)
        DH=HR/32. 0
C --- -----------------------------    KUTTA
  13    KC=4
  14    J=2
        GO TO 9
  20    KC=KC-1
        IF (KC. GE. 4)  GO TO 73
        IF (KC. LE. 0)  GO TO 2
  22    X=DH*0. 33333333E0
        N2=N+N
        GO TO (27, 23, 24), KC
  23    X=X+X
        N2=N
  24    DO 25 I=1, N
        I3=I+N2
        W(I3)=D(I)
   25  Y(I)=D(I)*X+W(I)
   26  T(1)=TR+X
       GO TO 14
C ---  ------------------------------   KUTTA FAIL
  250  DH=DH*0.25
       IF (DH*CH2.LT.HR)  GO TO 2
  251  KC=3
       X=DH*0.33333333E0
       DO 252 I=1,N
       I3=I+N2
  252  Y(I)=W(I3)*X+W(I)
       GO TO 26
C ---  ------------------------------   KUTTA TEST
   27  DO 270 I=1,N
       I2=N+I
       I3=N+I2
       X=DH*ABS((W(I3)-W(I2))-(W(I2)-D(I)))
       XA=ABS(Y(I))+CL
       IF (XA*CL.LE.X)  GO TO 250
  270  CONTINUE
C ---  ------------------------------   KUTTA COMPLETE
       DO 28 I=1,N
       I2=N+I
       I3=N+I2
       I4=N+I3
       XA=(D(I)-W(I2))*3.0
       X=W(I3)-W(I2)
       Y(I)=((XA+X)*0.25 +W(I2))*DH +W(I)
       X=(X*3.0+XA)*3.0/DH
       W(I4)=X/DH
       W(I2)=W(I3) +XA
   28  W(I3)=0.5*X+XA/DH
       TR=TR+DH
       HR=HR-DH
  280  DO 29 I=1,N
   29  W(I)=Y(I)
C ---  ------------------------------   PREDICTOR
  400  DH=AMIN1(HR,DH)
       X=HR/DH
       Z=X/ZT
       ZT=ZT+(Z*CL)**2
       IF (X.GT.CHF(4))  GO TO 404
       XA=AINT(X+CHM(1))
       DH=HR
       IF (XA.LT.CHM(4))  GO TO 404
       X=AMAX1(X,XA)
       DH=HR/X
  404  DH2=DH*0.5
       DH3=DH*0.333333
       DO 405 I=1,N
       I2=N+I
       I3=N+I2
       I4=N+I3
       D(I)=(DH2*W(I4)+W(I3))*DH+W(I2)
       Y(I)=( ( DH3  *W(I4)+W(I3))*DH2+W(I2))*DH+W(I)
       I5=I4+N
  405   W(I5)=Y(I)
```

```
      HH=DH*CH1
      T(1)=TR+DH
        L=. TRUE.
      J=4
      KC =6
   90 H( 1)=HH
    9 JJ(1)=J
      RETURN
C --- ----------------------------    J=5 ENTRY
   70 DO 71 I=1, N
      I2=N+I
      I3=N+I2
      I4=N+I3
      I5=I+N4
      XA=W(I5)
      IF (KC. EQ. 5)  XA
     1     =((DH3*W(I4)+W(I3))*DH2+W(I2))*DH+W(I)-XA
      X=Y(I)-XA
      Y(I)=XA
   71 IF (X. NE. 0. 0)  D(I)=D(I)+X/HH
      KC=KC-1
   73 L=KC. EQ. 5
C --- ----------------------------    J=2 AFTER 4          L=. FALSE.
C --- ----------------------------    J=2 INSTEAD OF 4     L=. TRUE.
   75 DO 78 I=1, N
      I2=N+I
      I3=N+I2
      I4=N+I3
      I5=I4+N
      X=((DH2*W(I4)+W(I3))*DH +(W(I2)-D(I))) *HH
      IF(L)  GO TO 77
      IF (W(I5). NE. 0. 0)  X=AMIN1(X/W(I5), CHF(3))
      X=X-2. 0
      D(I)=W(I5)+W(I5)/X
      Y(I)=Y(I)+D(I)
      GO TO 78
   77 Y(I)=W(I5)-X
      W(I5)=X
   78 CONTINUE
      IF (L)  GO TO 9
C --- ----------------------------    J=4 ENTRY
   40 K=4
      DO 409 I=1, N
      I5=I+N4
      X=D(I)
      IF(L)  X=Y(I)
  421 D(I)=X-W(I5)
  420 XA=((ABS(Y(I)-W(I))+CL)*Z+ABS(Y(I)))*CL
  402 IF (XA. GE. CHF(K)*ABS(D(I)))  GO TO 409
      K=K-1
      IF (K. EQ. 0)  GO TO 411
      GO TO 402
  409 CONTINUE
      XA=DH**3
      DO 41 I=1, N
      I2=N+I
      I3=N+I2
```

```
0158             I4=N+I3
0159             X=D(I)/XA
0160             W(I2)=((CHA(1)*X+W(I4))*DH2+W(I3))*DH+W(I2)
0161             W(I3)=(CHA(2)*X+W(I4))*DH+W(I3)
0162       41    W(I4)=CHA(3)*X+W(I4)
0163             TR=TR+DH
0164             HR=HR-DH
0165             DH=CHM(K)*DH
0166             IF (HR.GT.0.0)  GO TO 280
0167             T(1)=TE
0168             HH=HX
0169       31    J=3
0170             GO TO 90
0171       411   DH=DH*0.25
0172             IF (DH*CH2.LT.HR)  GO TO 2
0173             GO TO 400
0174             END


PROGRAM SECTIONS

    Name                                         Bytes   Attributes

  0 $CODE                                         2209   PIC CON REL LCL   SHR   EXE   RD
  2 $LOCAL                                         412   PIC CON REL LCL NOSHR NOEXE   RD

ENTRY POINTS

    Address  Type  Name                  Address  Type  Name

  0-00000083       AIR                 0-00000000       AIRY

VARIABLES

    Address  Type  Name                  Address  Type  Name                      Address  Typ

  2-00000030  R*4  CH1                 2-00000034  R*4  CH2                     2-0000003C  R*
  2-00000088  R*4  DH2                 2-0000008C  R*4  DH3                     2-00000094  R*
  2-00000060  R*4  HX                  2-0000004C  I*4  I                       2-0000007B  I*
  2-00000080  I*4  I4                  2-00000090  I*4  I5                      2-0000004B  I*
  2-00000068  I*4  KC                  2-0000002C  L*4  L                       2-00000038  I*
  2-00000040  I*4  N                   2-00000070  I*4  N2                      2-00000044  I*
  2-0000005C  R*4  TE                  2-00000054  R*4  TR                      2-0000006C  R*
  2-00000084  R*4  Z                   2-00000064  R*4  ZT

ARRAYS

    Address  Type  Name                      Bytes  Dimensions

  2-00000000  R*4  CHA                          12  (3)
  2-0000000C  R*4  CHF                          16  (4)
  2-0000001C  R*4  CHM                          16  (4)
```

```
                                                                  25-May-1983 17:04
                                                                  24-May-1983 09:52

        C
        C
        C
              FUNCTION BOUNDL(X)
              IMPLICIT REAL*8 (A-H,O-Z)
        C
        C      DEFINITION OF THERMAL INTERNAL BOUNDARY LAYER
        C      JUST A SIMPLE CURVE FIT
        C
              IF(X.LT.0.) X=0.
              IF(X.GT.1000.) X=1000.
              A=-0.0555
              B=10.555
              BOUNDL=A*X+B*SQRT(X)
              RETURN
              END


PROGRAM SECTIONS

    Name                                      Bytes   Attributes

  0 $CODE                                        95   PIC CON REL LCL   SHR   EXE   RD
  2 $LOCAL                                       24   PIC CON REL LCL NOSHR NOEXE   RD

ENTRY POINTS

    Address   Type  Name

  0-00000000  R*8   BOUNDL

VARIABLES

    Address   Type  Name                Address   Type  Name                Address   Ty

  2-00000008  R*8   A                 2-00000010  R*8   B                 AP-00000004@ R

FUNCTIONS AND SUBROUTINES REFERENCED

MTH$DSQRT

Total Space Allocated = 119 Bytes
```

25-May-1983 17:03
25-May-1983 15:20

```
            SUBROUTINE CG
            IMPLICIT REAL*8 (A-H,O-Z)
            INCLUDE 'NEWD.CMN'
 * C
 * C  NEW NODE DEFINITION
 * C
 *          COMMON/NEWD/ NEWNODE(1000,4),XNEW(4000),YNEW(4000),
 *         1NEWFROM(1000),NNN,NNODE
 * C
 * C     NNN= NUMBER OF ELEMENTS NEW (SUBDIVIDED) DATA
 * C     NNODE=NUMBER OF NODES IN NEW (SUBDIVIDED) DATA
 * C     NEWFROM(I) = INDEX OF ORIGINAL ELEMENT IN WHICH 'I' IS
 * C
 *
            INCLUDE 'PARA.CMN'
 * C         COMMON PARA IS THE MAIN PARAMETER BLOCK
 * C         -CGX,CGY ARE THE LOCATIONS OF THE CG OF
 * C          THE AREA BEING REPRESENTED
 * C         -POP IS THE POPULATION REPRESENTED AT THE CG (IN # OF PEOPLE)
 * C         -AREA IS THE AREA OF THE REPRESENTED ELEMENT OF TERRAIN(KM**2)
 * C         -ELEV IS ELEVATION OF AREA
 * C         -H IS THE EFFECTIVE RELEASE HEIGHT
 * C         -XCORD,YCORD ARE THE COMPONENTS FOR THE CONCENTRATION CALC
 * C
 *          COMMON /PARA/ CGX(1000),CGY(1000),AREA(1000),POP(1000)
 *         Z,ELEV(1000),NP,H(1000),CONC(1000),XCORD(1000),YCORD(1000)
            DO 10 I=1,NNN
            IT=4
            IF(NEWNODE(I,4).EQ.0) IT=3
            SUMX=0.
            SUMY=0.
            DO 1 K=1,IT
            J=NEWNODE(I,K)
            SUMX=SUMX+XNEW(J)
            SUMY=SUMY+YNEW(J)
          1 CONTINUE
            CGX(I)=SUMX/FLOAT(IT)
            CGY(I)=SUMY/FLOAT(IT)
         10 CONTINUE
            RETURN
            END
```

```
  C
  C        - ROUTINUE TO CALCULATE THE X AND Y COMPONENTS
  C          OF CG POSITION RELATIVE TO THE WIND DIRECTION
  C
                SUBROUTINE CONVERT(ISOURCE)
                IMPLICIT REAL*8 (A-H,O-Z)
                INCLUDE 'NEWD.CMN'
* C
* C   NEW NODE DEFINITION
* C
*               COMMON/NEWD/ NEWNODE(1000,4),XNEW(4000),YNEW(4000),
*              1NEWFROM(1000),NNN,NNODE
* C
* C         NNN= NUMBER OF ELEMENTS NEW (SUBDIVIDED) DATA
* C         NNODE=NUMBER OF NODES IN NEW (SUBDIVIDED) DATA
* C         NEWFROM(I) = INDEX OF ORIGINAL ELEMENT IN WHICH 'I' IS
* C
*
                INCLUDE 'PARA.CMN'
* C              COMMON PARA IS THE MAIN PARAMETER BLOCK
* C              -CGX,CGY ARE THE LOCATIONS OF THE CG OF
* C               THE AREA BEING REPRESENTED
* C              -POP IS THE POPULATION REPRESENTED AT THE CG (IN # OF PEOPLE)
* C              -AREA IS THE AREA OF THE REPRESENTED ELEMENT OF TERRAIN(KM**2)
* C              -ELEV IS ELEVATION OF AREA
* C              -H IS THE EFFECTIVE RELEASE HEIGHT
* C              -XCORD,YCORD ARE THE COMPONENTS FOR THE CONCENTRATION CALC
* C
*               COMMON /PARA/ CGX(1000),CGY(1000),AREA(1000),POP(1000)
*              Z,ELEV(1000),NP,H(1000),CONC(1000),XCORD(1000),YCORD(1000)
                INCLUDE 'ATMOS.CMN'
* C
* C             ATMOS CONTAINS ALL PERTINENT DATA FOR CONCENTRATION
* C             CALCULATIONS AND DETERMINATION OF SIGMA'S
* C
*               COMMON /ATMOS/ GRATE(100),USPEED,HEIGHT(100),SIGY,
*              ZSIGZ,SIGTHETA,SIGPHI,XT,RT,HT,C,AO,XLS(100),
*              ZELEVSOUR(100),XLID,WDIR,SX(100),SY(100),
*              ZILAKE,IWCLASS2,NSOURCE
                DATA PI/3.14159265/
                DO 10 I=1,NP
                R=SQRT((CGX(I)-SX(ISOURCE))**2+(CGY(I)-SY(ISOURCE))**2)
                THETA=ASIN((CGX(I)-SX(ISOURCE))/R)
                IF((CGY(I)-SY(ISOURCE)).LT.0.) THETA=PI-THETA
                PHI=ABS(WDIR-THETA)
                IF(PHI.GT.PI) PHI=2.*PI-PHI
                XCORD(I)=R*COS(PHI)
                YCORD(I)=R*SIN(PHI)
          10    CONTINUE
                RETURN
                END
```

```
      SUBROUTINE DEFOLT
C     ******************
C
      DIMENSION W(6, 2), NWEL(6), WEL(4, 6)
C
      REAL MASS
      CHARACTER*8 TITLE
      INTEGER A, ZON, WIND, CAT
C
      COMMON/BAT/SIGTH, SIGTV, SIG3H, SIG3V, CAY, TEMP
      COMMON/AAA/XS, XT, HT, XA, POPDIS(20, 20), TX, A, J, XGRID(80), SHINT, NINT
      COMMON/BBB/ZO, ZON, WIND, MASS, PI, UZC, RO, HO, VO, G, RHO, RHOA, VEL(4, 6),
     *UZM, UAV, USTAR, XK, XL
      COMMON/HEET/ALPH, CAIR, CGAS, TAIR, RHOGAS, TGROUND(6, 4), ALSTAR, ALPI
      COMMON/CCC/CAS(3, 12, 4, 6), P(12, 4, 6), MNO, CAT, ZM, TT, NST(50), TCEN(50)
      COMMON/FFF/TA, TR, NVEL(6), NPOINT, NSEC, HTP, ALIM, NG
      COMMON/EXTRA/AMASS, ARE, NFN, NHEAT, TEK(80), ROA(80), HRATE(80), CMASS,
     *NRANGE, DELRHO(80), AIRM(80), VELRAT(80), RICH(80), NENT
      COMMON/RITE/NALL, TITLE(13)
C
      DATA WEL/1.5, 3*0., 3.0, 3*0., 3.0, 3*0., 6.0, 3.0, 2*0., 3.0, 3*0., 2.0, 3*0.
     */
      DATA NWEL/1, 1, 1, 2, 1, 1/
      DATA W/1.67E-03, 5.83E-03, 1.25E-02, 2.67E-02, 5.0E-03, 5.0E-03, 3*0.,
     *2.67E-02, 2*0./
      DATA TITLE/'DENZ    ', 'A PROGRA', 'M TO CAL', 'CULATE T',
     *'HE CONSE', 'QUENCES ', 'OF PUFF ', 'RELEASES', ' OF INIT',
     *'IALLY DE', 'NSER-THA', 'N-AIR GA', 'SES     '/
C
C
C     THIS SUBROUTINE PROVIDES DEFAULT VALUES FOR SOME OPTION CARDS
C
C     DEFAULT POPULATION DISTRIBUTION
      NPOINT=20
      NSEC=12
      NG=NSEC+1
      DO 1 J=1, NPOINT
      POPDIS(J, 13)=500. *FLOAT(J)-250.
      DO 2 K=1, NSEC
      POPDIS(J, K)=1.
2     CONTINUE
1     CONTINUE
C
C     HEIGHT OF WIND, ROUGHNESS LENGTH AND CATEGORY
      ZM=10.
      ZO=0.1
      ZON=3
C
C     DEFAULT WEATHER DATA
      DO 3 I=1, 6
      NVEL(I)=NWEL(I)
      NV=NVEL(I)
      DO 4 NN=1, NV
      DO 5 K=1, 12
      DO 6 J=1, 4
      VEL(J, I)=WEL(J, I)
      P(K, NN, I)=W(I, NN)
```

```
6       CONTINUE
5       CONTINUE
4       CONTINUE
        DO 7 L=1,4
        TGROUND(I,L)=293.0
7       CONTINUE
3       CONTINUE
C
C       CUT-OFF HEIGHT FOR SLUMPING AND END OF STAGE 3
        HTP=0.5
        ALIM=0.001
C
C       NO F-N LINES,NO HEATING,HEIGHT EQUAL TO RADIUS
C       RANGE NOT CALCULATED
C       COX AND ROE ENTRAINMENT CRITERION,NO EDGE ENTRAINMENT,
C       TOP ENTRAINMENT COEFFICIENT=0.5
C       VAN ULDEN(S CONSTANT=1
        NFN=0
        NHEAT=0
        ARE=-1.
        NRANGE=0
        NALL=0
        NENT=1
        ALSTAR=0.
        ALPI=0.5
        TAIR=293.
        CAY=1.
C
        RETURN
        END
%FORT-W-ERROR 124, Mixed numeric and character elements in COMMON
        [RITE] in module DEFOLT
```

```
      C
      C       ROUTINE TO DUMP OUTPUT AFTER EACH CASE AND AT THE END OF THE RUN
      C
             SUBROUTINE DOCOUT(ICASE, ISOURCE)
             IMPLICIT REAL*8 (A-H, O-Z)
             INCLUDE 'PARA.CMN'
    * C       COMMON PARA IS THE MAIN PARAMETER BLOCK
    * C       -CGX,CGY ARE THE LOCATIONS OF THE CG OF
    * C        THE AREA BEING REPRESENTED
    * C       -POP IS THE POPULATION REPRESENTED AT THE CG (IN # OF PEOPLE)
    * C       -AREA IS THE AREA OF THE REPRESENTED ELEMENT OF TERRAIN(KM**2)
    * C       -ELEV IS ELEVATION OF AREA
    * C       -H IS THE EFFECTIVE RELEASE HEIGHT
    * C       -XCORD,YCORD ARE THE COMPONENTS FOR THE CONCENTRATION CALC
    * C
    *        COMMON /PARA/ CGX(1000),CGY(1000),AREA(1000),POP(1000)
    *       Z,ELEV(1000),NP,H(1000),CONC(1000),XCORD(1000),YCORD(1000)
             INCLUDE 'ATMOS.CMN'
    * C
    * C      ATMOS CONTAINS ALL PERTINENT DATA FOR CONCENTRATION
    * C      CALCULATIONS AND DETERMINATION OF SIGMA'S
    * C
    *        COMMON /ATMOS/ QRATE(100),USPEED,HEIGHT(100),SIGY,
    *       ZSIGZ,SIGTHETA,SIGPHI,XT,RT,HT,C,AO,XLS(100),
    *       ZELEVSOUR(100),XLID,WDIR,SX(100),SY(100),
    *       ZILAKE,IWCLASS2,NSOURCE
             IF(ICASE.EQ.0) RETURN
             IF(ISOURCE.EQ.NSOURCE) THEN
                      WRITE(3,10) ICASE
          10          FORMAT('1',///,20X,'CUMMULATIVE CONCENTRATIONS '
            Z         ,'FOR CASE NO.  ',I4,///)
                  ELSE
                      WRITE(3,13) ISOURCE
          13          FORMAT('1',///,15X,'CONCENTRATIONS '
            Z         ,'FOR SOURCE ',I4,///)
                      ENDIF
             WRITE(3,20)
          20 FORMAT(5(4X,'LOC.',7X,'CONC',4X),/,
            Z5(1X,'   NO.   ',14X),/)
             DO 15 I=1,NP,5
             N=5
             IF((I+5).GT.1000) N=6-(I+5-1000)
             N=N+I-1
             WRITE(3,14) (J,CONC(J),J=I,N)
          14 FORMAT(5(2X,I6,2X,G13.6))
          15 CONTINUE
             RETURN
             END
```

```
                                                        25-May-1983 17:04
                                                        24-May-1983 09:52

      C
      C
      C
                FUNCTION EQN(XDUM, I, XIC)
                IMPLICIT REAL*8 (A-H, O-Z)
                INCLUDE 'ATMOS.CMN'
    * C
    * C         ATMOS CONTAINS ALL PERTINENT DATA FOR CONCENTRATION
    * C         CALCULATIONS AND DETERMINATION OF SIGMA'S
    * C
    *           COMMON /ATMOS/ GRATE(100), USPEED, HEIGHT(100), SIGY,
    *          ZSIGZ, SIGTHETA, SIGPHI, XT, RT, HT, C, AO, XLS(100),
    *          ZELEVSOUR(100), XLID, WDIR, SX(100), SY(100),
    *          ZILAKE, IWCLASS2, NSOURCE
                INCLUDE 'PARA.CMN'
    * C          COMMON PARA IS THE MAIN PARAMETER BLOCK
    * C          -CGX, CGY ARE THE LOCATIONS OF THE CG OF
    * C           THE AREA BEING REPRESENTED
    * C          -POP IS THE POPULATION REPRESENTED AT THE CG (IN # OF PEOPLE)
    * C          -AREA IS THE AREA OF THE REPRESENTED ELEMENT OF TERRAIN(KM**2)
    * C          -ELEV IS ELEVATION OF AREA
    * C          -H IS THE EFFECTIVE RELEASE HEIGHT
    * C          -XCORD, YCORD ARE THE COMPONENTS FOR THE CONCENTRATION CALC
    * C
    *           COMMON /PARA/ CGX(1000), CGY(1000), AREA(1000), POP(1000)
    *          Z, ELEV(1000), NP, H(1000), CONC(1000), XCORD(1000), YCORD(1000)
                IF(XDUM.LT.0.) XDUM=0.
                CALL SIG(XDUM, YCORD(I))
                XX=XDUM+XLS(ISOURCE)
                EQN=BOUNDL(XX)-H(I)+2.5*SIGZ*XIC
                RETURN
                END
```

```
                                                                    25-May-1983 17:05:
                                                                    19-Apr-1983 14:22:
        C
        C
              FUNCTION EQN2(VVVV,COV)
              IMPLICIT REAL*8 (A-H,O-Z)
              REAL*8 K2,K1
              K2=1.+2./VVVV
              K1=1.+1./VVVV
              EQN2=DSQRT(GAM(K2)/GAM(K1)**2.-1.)-COV
              RETURN
              END


PROGRAM SECTIONS

    Name                                         Bytes   Attributes

  0 $CODE                                          74    PIC CON REL LCL   SHR   EXE    RD
  2 $LOCAL                                         40    PIC CON REL LCL NOSHR NOEXE    RD

ENTRY POINTS

    Address   Type  Name

  0-00000000  R*8   EQN2

VARIABLES

    Address   Type  Name              Address   Type  Name                Address   Ty

 AP-00000008@ R*8   COV             2-00000010  R*8   K1                2-00000008  R

FUNCTIONS AND SUBROUTINES REFERENCED

GAM             MTH$DSQRT

Total Space Allocated = 114 Bytes
```

```
C
      SUBROUTINE FANDG(X,SIGMAZ,B)
C     ************************************************
C     TO CALCULATE (GIVEN X) THE VALUES F(ZO,X),G(X) AND SIGMAZ
C     FROM HOSKER(S FORMULAE
C
      DIMENSION CGX(6,4),CFX(6,4)
C
      INTEGER B,ZON,WIND
      REAL MASS
C
      COMMON/BBB/ZO,ZON,WIND,MASS,PI,UZC,RO,HO,VO,G,RHO,RHOA,VEL(4,6),
     *UZM,UAV,USTAR,XK,XL
C
      DATA CGX,CFX/.112,.130,.112,.098,.0609,.0638,1.06,.95,.92,.889,
     *.895,.783,5.38,6.52,9.05,13.5,19.6,13.6,.815,.75,.718,.688,.684,
     *.672,1.56,2.02,2.72,5.16,7.37,11.7,0.048,.0269,0.,-0.098,-.0957,
     *-.128,6.25E-04,7.76E-04,0.,18.6,4290.,45900.,0.45,0.37,0.,-0.225,
     *-.6,-0.78/
C
      U2=CGX(B,1)*X**CGX(B,2)
      V2=1+CGX(B,3)*(X**CGX(B,4))*1.E-04
      GX=U2/V2
      IF(ZON-3)2,4,1
    4 FX=1.
      GOTO5
    1 ARG=X**CFX(ZON,2)+X**(CFX(ZON,2)-CFX(ZON,4))/CFX(ZON,3)
      GO TO 3
    2 ARG1=(1.+CFX(ZON,3)*X**CFX(ZON,4))**(-1)
      ARG=X**CFX(ZON,2)*ARG1
    3 FX=ALOG(ARG*CFX(ZON,1))
    5 CONTINUE
      SIGMAZ=FX*GX
      RETURN
      END
```

```
                                                              25-May-1983 17:07:
                                                              24-May-1983 10:06:

0001              SUBROUTINE FLARE(ISOURCE)
0002              IMPLICIT REAL*8 (A-H,O-Z)
        C
        C          ROUTINE FOR FLARE EFFECTS
        C
0003              INCLUDE 'OPTIONS.CMN'
      * C
      * C          OPTIONS CONTAIN ALL OPTIONS REQUIRED FOR EXECUTION
      * C
0004  *           COMMON /OPTIONS/ IOPTION(11),IRUNCODE
      * C          IOPTION IS DEFINED AS FOLLOWS :
      * C                    IOPTION(1)  : PLUME MODEL=1; PUFF .NE. 1; IN/OUTDOOR=3
      * C                    IOPTION(2)  : SIGMA Y,Z OPTIONS 1,2,OR 3
      * C                    IOPTION(3)  : WEATHER CLASS (1=A,2=B,...6=F)
      * C                    IOPTION(4)  : TERRAIN ROUGHNESS(1,2,...6)
      * C                    IOPTION(5)  : GRAVITY EFFECT OPTION (1=INCLUDE)
      * C                    IOPTION(6)  : BUILDING EFFECT OPTION (1=INCLUDE)
      * C                    IOPTION(7)  : TERRAIN MODIFICATION (1=INCLUDE)
      * C                    IOPTION(8)  : TRAPPING OPTION (1=INCLUDE)
      * C                    IOPTION(9)  : LAKE BREEZE EFFECT (1=INCLUDE)
      * C                    IOPTION(10) : DEBUGGING SWITCH 1= ADDITIONAL OUTPUT
      * C                                                  2= TERRAIN PLOT PRODUCED
      * C                    IOPTION(11) : RELEASE TYPE 1=PASSIVE
      * C                                               2=VERTICAL JET
      * C                                               3=FLARE
      * C                                               4=HEAVIER THAN AIR
0005              INCLUDE 'PUFF.CMN'
      * C
      * C          PUFF CONTAINS THE PUFF MODEL SPECIFIC SOURCE ARRAYS
      * C
0006  *           COMMON /PUFF/ PUFFT(100,100),PUFFQ(100,100),TAUB,TAU
0007              INCLUDE 'ATMOS.CMN'
      * C
      * C         ATMOS CONTAINS ALL PERTINENT DATA FOR CONCENTRATION
      * C         CALCULATIONS AND DETERMINATION OF SIGMA'S
      * C
0008  *           COMMON /ATMOS/ QRATE(100),USPEED,HEIGHT(100),SIGY,
      *          ZSIGZ,SIGTHETA,SIGPHI,XT,RT,HT,C,AO,XLS(100),
      *          ZELEVSOUR(100),XLID,WDIR,SX(100),SY(100),
      *          ZILAKE,IWCLASS2,NSOURCE
0009              INCLUDE 'RELTYPE.CMN'
0010  *           COMMON /RELTYPE/ DISCH(100),WO,SO2FLOW(100),DTHDZ,ALPHA,
      *          ZU10,CFLARE,AMTEMP
0011              INCLUDE 'DISPD.CMN'
      * C          FACTORS FOR DISPERSION COEFFICIENTS
      * C
      * C    AA1,AA2,BB1,BB2,CC3 ARE FUNCTION OF WEATHER CLASS
      * C    CC1,CC2,DD1,DD2,     ARE FUNCTIONS OF ROUGHNESS
      * C
0012  *           COMMON/DISPD/ AA1(6),AA2(6),BB1(6),BB2(6),CC1(6)
      *          1,CC2(6),CC3(6),DD1(6),DD2(6),ZO(6)
0013              IF(IOPTION(1).NE.1) THEN
        C
        C          INTEGRATE UP THE PUFFS FOR AN AVERAGE VALUE OF QRATE
        C
0014              TOT=0.
0015              DO 10 IPUFF=1,100
```

```
      IF(PUFFQ(ISOURCE, IPUFF). LE. 0. ) GO TO 14
      TOT=TOT+PUFFQ(ISOURCE, IPUFF)
   10 CONTINUE
   14 CONTINUE
      IPUFF=IPUFF-1
      QRATE(ISOURCE)=TOT/PUFFT(ISOURCE, IPUFF)
      ENDIF
      F=CFLARE*QRATE(ISOURCE)
      SCON=9. 8/AMTEMP*DTHDZ
      IF(IOPTION(3). GT. 5) GO TO 101
      IF(F. LE. 55. ) THEN
           XSTAR=14. *F**0. 625
         ELSE
           XSTAR=34. *F**0. 4
         ENDIF
      U=USPEED
      IF(U. LT. 0. 5) U=0. 5
      DELH=1. 6*F**0. 33333/U*(3. 5*XSTAR)**0. 66666
      IF(IOPTION(3). LT. 5) GO TO 11
      IF(USPEED. LE. 0. 5) THEN
                DELH2=5. 3*F**0. 25/SCON**0. 375
             ELSE
                DELH2=2. 6*(F/USPEED/SCON)**0. 33333
             ENDIF
      IF(DELH2. LT. DELH) DELH=DELH2
      GO TO 11
  101 CONTINUE
      IF(USPEED. LE. 0. 5) THEN
                DELH=5. 3*F**0. 25/SCON**0. 375
             ELSE
                DELH=2. 6*(F/USPEED/SCON)**0. 33333
             ENDIF
   11 CONTINUE
      HEIGHT(ISOURCE)=HEIGHT(ISOURCE)+DELH
      USTAR=USPEED*0. 4/LOG(10. /ZO(IOPTION(4)))
      XDUM=3. 1415926*HEIGHT(ISOURCE)/USTAR/USTAR*F/SO2FLOW(ISOURCE)
      IF(XDUM. LT. 10. ) HEIGHT(ISOURCE)=0.
C
C      ADJUST USPEED TO EFFECTIVE STACK HEIGHT
C
      IF(HEIGHT(ISOURCE). LE. 10. ) GO TO 12
      IF(HEIGHT(ISOURCE). LE. 50. ) THEN
                           USTAR=U10*0. 4/LOG(10. /ZO(IOPTION(4)))
                           USPEED=USTAR/0. 4*LOG(HEIGHT(ISOURCE)
     Z                                /ZO(IOPTION(4)))
                       ELSE
                           USPEED=U10*(HEIGHT(ISOURCE)/10. )**ALPHA
                       ENDIF
   12 CONTINUE
      RETURN
      END
```

```
                                                                   25-May-1983 17:06:
                                                                   24-May-1983 09:48:

0001          SUBROUTINE HAIR(Y,D,W,H,T,NN,J)
0002          DIMENSION Y(NN),D(NN),W(5000),H(1),T(1),J(1)
0003          LOGICAL L4,L42
0004          DATA M/16/
      C --- -----------------------------   VERSION OF 06NOV68
0005          IF (J(1).EQ.3)  L42=.FALSE.
0006          IF (J(1).EQ.2 .AND. L4)  L42=.TRUE.
0007          IF (J(1).NE.1)  GO TO 19
0008          L42=.FALSE.
0009          N=NN
0010          CALL AIRY(Y,D,W,H,T,N,J,M)
0011     19   IF (J(1).EQ.5) J(1)=2
0012     1    CALL AIR
0013          L4=.FALSE.
0014          IF (J(1).EQ.4 .AND. L42)  J(1)=2
0015          IF (J(1).NE.4)  GO TO 9
0016          DO 11 I=1,N
0017     11   D(I)=Y(I)-H(1)*D(I)
0018          L4=.TRUE.
0019     9    RETURN
0020          ENTRY HAIRY(MM)
0021          M=MM
0022          RETURN
0023          END


PROGRAM SECTIONS

    Name                                        Bytes   Attributes

  0 $CODE                                         337   PIC CON REL LCL    SHR    EXE   RD
  2 $LOCAL                                        268   PIC CON REL LCL NOSHR  NOEXE   RD

ENTRY POINTS

    Address  Type  Name                  Address  Type  Name

  0-00000000       HAIR                0-0000011A       HAIRY

VARIABLES

    Address  Type  Name                  Address  Type  Name                  Address  Typ

  2-00000010  I*4  I                   2-00000000  L*4  L4                  2-00000004  L
 AP-00000004@ I*4  MM                  2-0000000C  I*4  N                  AP-00000018@ I
```

```
      SUBROUTINE HEAVY(TRANSFER)
C
C     ROUTINE TO CALCULATE THE DISPERSION OF DENSE GASES
C
      DIMENSION ABY(3, 50), SUMS(3), RANGE(3), HLV(3, 50)
C
      CHARACTER*4 ABC, EN
      INTEGER A, ZON, WIND, CAT, PR
      REAL*8 TRANSFER(5)
      REAL MASS
C
      COMMON/BAT/SIGTH, SIGTV, SIG3H, SIG3V, CAY, TEMP
      COMMON/AAA/XS, XT, HT, XA, POPDIS(20, 20), TX, A, J, XGRID(80), SHINT, NINT
      COMMON/BBB/ZO, ZON, WIND, MASS, PI, UZC, RO, HO, VO, G, RHO, RHOA, VEL(4, 6),
     *UZM, UAV, USTAR, XK, XL
      COMMON/HEET/ALPH, CAIR, CGAS, TAIR, RHOGAS, TGROUND(6, 4), ALSTAR, ALPI
      COMMON/CCC/CAS(3, 12, 4, 6), P(12, 4, 6), MNO, CAT, ZM, TT, NST(50), TCEN(50)
      COMMON/EEE/HEIGHT(50), RADIUS(50), UVEL(50), TAU(50), CONC(50)
      COMMON/FFF/TA, TR, NVEL(6), NPOINT, NSEC, HTP, ALIM, NG
      COMMON/GGG/NHAZ, NTYPE, NTIME(3), TOXIC(50, 3), TEXP(50, 3), HLEV(3),
     *TAW, EKONK, PR(3)
      COMMON/XYZ/NWRITE
      COMMON/TIME/TTR
      COMMON/EXTRA/AMASS, ARE, NFN, NHEAT, TEK(80), ROA(80), HRATE(80), CMASS,
     *NRANGE, DELRHO(80), AIRM(80), VELRAT(80), RICH(80), NENT
      COMMON/RITE/NALL, TITLE(13)
      COMMON/SOURCE/FMASS, FRHO, FTEMP
C
      DATA EN/'END '/
C
      NCONT=0
      NINT=48
      CALL READIN(NCONT)
  314 CONTINUE
      SHINT=ALOG(POPDIS(NPOINT, NG))/(NINT+1)*1. 5
      WRITE(3, 3)SHINT
    3 FORMAT(1H0, 'GRID INTERVAL IN LN(X) IS', E12. 4)
C
C      CALCULATE INITIAL VALUES
      VO=(FMASS+AMASS)/FRHO
      RO=(VO/PI)**0. 3333
      IF(ARE. GT. 0) RO=SQRT(ARE/PI)
      RAD=RO**2
      HO=VO/(PI*RO**2)
      WRITE(36, 61)VO, HO, RO
   61 FORMAT(1H0, 'INITIAL DIMENSIONS OF CLOUD'/
     *' VOLUME=', E10. 3, ' M**3,HEIGHT=', E10. 3, ' M,RADIUS=', E10. 3, ' M')
C
C      INITIALISE ARRAY CAS
      DO 23 III=1, 12
      DO 24 LLL=1, 3
      DO 25 JJJ=1, 6
      DO 26 KKK=1, 4
      CAS(LLL, III, KKK, JJJ)=0.
   26 CONTINUE
   25 CONTINUE
   24 CONTINUE
```

```
23    CONTINUE
C
C     BEGIN WEATHER CATEGORY LOOP
      DO 98 CAT=1,6
      NZ=NVEL(CAT)
      IF(NZ.EQ.0)GO TO 98
      A=CAT
C
C     BEGIN VELOCITY SUBDIVISION LOOP
      DO 97 MNO=1,NZ
      JQR=NINT
C
C     SET INITIAL VALUES
      NODIFF=0
      NWRITE=0
      RAD=RO**2
      CMASS=AMASS
      TEMP=FTEMP
      MASS=FMASS
      RHO=FRHO
C     AMASS IS THE MASS OF AIR IN THE SOURCE CYLINDER
C     CMASS IS THE MASS OF AIR IN THE CLOUD
C     FMASS IS THE MASS OF GAS IN THE SOURCE CYLINDER
C     MASS IS THE MASS OF GAS IN THE CLOUD
C     FTEMP IS THE TEMPERATURE OF THE SOURCE CYLINDER
C     TEMP IS THE TEMPERATURE OF THE CLOUD
C     FRHO IS THE DENSITY OF THE SOURCE CYLINDER
C     RHO IS THE DENSITY OF THE CLOUD
      DENDIF=FRHO-RHOA
      IF(DENDIF.LT.1.E-5)NODIFF=1
      DO 63 JF=1,50
      TEK(JF)=0.
      ROA(JF)=0.
      DELRHO(JF)=0.
      HRATE(JF)=0.
      AIRM(JF)=0.
      VELRAT(JF)=0.
      RICH(JF)=0.
63    CONTINUE
      IF(NALL.EQ.1)NWRITE=1
      IF(A.EQ.2.AND.MNO.EQ.1) NWRITE=1
      IF(A.EQ.1.AND.MNO.EQ.1) NWRITE=1
      IF(A.EQ.4.AND.MNO.EQ.2) NWRITE=1
      IF(A.EQ.6.AND.MNO.EQ.1) NWRITE=1
      IF(NWRITE.EQ.0.AND.NFN.EQ.0)GO TO 97
C
      UZM=VEL(MNO,CAT)
      IF(NWRITE.EQ.1)WRITE(3,4)CAT,UZM
4     FORMAT(1H0,30X,'WEATHER CATEGORY',I2,' WINDSPEED',E10.3,' M/SEC.'
     */,30X,25(2H**))
      USTAR=0.4*UZM/ALOG(ZM/ZO)
      UZC=USTAR*ALOG(HO/2./ZO)/0.4
C     UZC IS THE CLOUD VELOCITY
      UVEL(1)=UZC
C
      IF(NODIFF.EQ.1)GO TO 6
C     INITIAL CLOUD DENSITY IS THE SAME AS THAT OF
```

```
C     THE SURROUNDING AIR
      HT=4. *UZM**2*. 16*RHOA/((RHO-RHOA)*G*(ALOG(ZM/ZO))**2)
C     HT IS THE HEIGHT OF THE CLOUD WHEN THE TURBULENT ENERGY EQUALS
C     THE POTENTIAL ENERGY DIFFERENCE BETWEEN THE CLOUD AND THE AIR
      IF(HT. LT. HTP)HT=HTP
      RTSQD=VO/(PI*HT)
      RT=SQRT(RTSQD)
      SIGTH=RT/2. 14
      SIGTV=HT/2. 14
      TTR=   (RTSQD-RO**2)/(2. *CAY*SQRT(G*(RHO-RHOA)*VO/(PI*RHOA)))
      TT=0.
C     TTR IS THE TIME TAKEN TO SLUMP TO HEIGHT HT, ASSUMING
C     NO CHANGE IN CLOUD DENSITY
      NSTAGE=2
C
      GO TO 5
6     CONTINUE
      SIG3V=HO/2. 14
      SIG3H=RO/2. 14
      XA=0.
      TA=0.
      NSTAGE=4
C     INITIALISE PARAMETERS FOR ENTRY TO STAGE 4, SINCE
C     CLOUD HAS THE SAME DENSITY AS AIR
      IF(NWRITE. EQ. 1)WRITE(3,116)
116   FORMAT(1HO, 'THE INITIAL DENSITY OF THE CLOUD IS',
     *' THE SAME AS THAT OF THE SURROUNDING AIR', /, 1X,
     *'IT IS ASSUMED TO DIFFUSE PASSIVELY FROM TIME ZERO')
5     CONTINUE
C
C     BEGIN GRID LOOP
      DO 101 J=1, NINT
      TR=TT
      XK=EXP((J-1)*SHINT)
      XGRID(J)=XK
      IF(J. EQ. 1) TT=XK/UZC
      IF(J. GE. 2) XL=EXP((J-2)*SHINT)
      IF(J. GE. 2) TT=TT+(XK-XL)/UZC
      TCEN(J)=TT
      GOTO(102, 102, 103, 104), NSTAGE
C
C     THE START OF STAGE 2.
102   CONTINUE
      IF(TT. GT. TTR. AND. NHEAT. EQ. 0. AND. NENT. EQ. 0) GOTO 105
      IF(NHEAT. EQ. 0. AND. NENT. EQ. 0)CALL STAGE2(HALFHT)
      IF(NHEAT. NE. 0. OR. NENT. NE. 0)CALL HSTAG2(RAD, NSTAGE, HALFHT)
      IF(HALFHT. LE. ZO)GO TO 112
C     HALFHT IS THE HEIGHT OF THE CLOUD/2
C     IF HALFHT IS LESS THAN ZO THE MODEL IS NOT VALID
      IF(NSTAGE. EQ. 4) JGR=J-1
      IF(NSTAGE. EQ. 4)GO TO 104
      NST(J)=2
      GO TO 108
C
105   CONTINUE
C     CALCULATE THE CHANGEOVER VALUE(XT)FROM STAGE2 TO STAGE3.
      IF(J. EQ. 1)XT=UZC*TTR
      IF(J.GT.1) XT=XK-UZC*(TT-TTR)
      XS=XT
C
C     CHANGEOVER FROM STAGE 2 TO STAGE 3
      NSTAGE=3
103   CONTINUE
      NST(J)=3
      CALL STAGE3(HALFHT)
      IF(HALFHT.LE.ZO)GO TO 112
      CVOL=PI*RADIUS(J)*RADIUS(J)*HEIGHT(J)
C     TOTAL CLOUD VOLUME
      CEXVOL=CVOL-VO
C     INCREASE IN CLOUD VOLUME FROM TIME OF FORMATION OF SOURCE CYLINDER
      CMASS=AMASS+CEXVOL*RHOA
C     MASS OF AIR IN CLOUD
      CMS=MASS+CMASS
C     TOTAL CLOUD MASS
      RHOC=CMS/CVOL
C     CLOUD DENSITY
      RDIFF=RHOC-RHOA
      IF(RDIFF.LE.ALIM)GO TO 106
C     RDIFF IS THE CENTRE LINE DENSITY DIFFERENCE
      GO TO 108
C
106   CONTINUE
C     CALCULATE CHANGEOVER VALUES(FROM ST.3 TO ST.4)
      XA=EXP((J-1)*SHINT)
      TKP=TT
      CALL TRANS
      TT=TKP
C
C      CHANGEOVER TO STAGE 4
      NSTAGE=4
104   CONTINUE
      NST(J)=4
      IF(TT.LT.TA)GO TO 17
C
C      PASSIVE CLOUD
      CALL STAGE4
      TRANSFER(1)=XGRID(J)
      TRANSFER(2)=HEIGHT(J)
      TRANSFER(3)=RADIUS(J)
      TRANSFER(4)=CONC(J)
      TRANSFER(5)=FMASS
      WRITE(1,10)TRANSFER
      WRITE(3,10)TRANSFER
   10 FORMAT(' TRANSFER = ',5(G12.5,2X))
      STOP
C
17    CONTINUE
C
108   CONTINUE
C     END OF DO LOOP FOR THE GRID
C
101   CONTINUE
C
      IF(NWRITE.EQ.0)GO TO 97
```

```
             IF(NODIFF. EQ. 1)GO TO 27
             WRITE(3, 107)
      107    FORMAT(1H0, 'TRANSITION PARAMETERS'/11(2H**))
             IF(NENT. EQ. 0. AND. NHEAT. EQ. 0)WRITE(3, 109)XT, HT, RT, SIGTH, SIGTV, TTR
      109    FORMAT(1H0, 'TRANSITION POINT FROM STAGE 2 TO STAGE 3 IS AT', E10. 3,
            *' METRES'/' HEIGHT AND RADIUS ARE', 2E10. 3, ' METRES RESPECTIVELY'
            */' VIRTUAL SOURCE HORIZONTAL AND VERTICAL STANDARD DEVIATIONS ARE'
            *, 2E10. 3, ' METRES RESPECTIVELY'/, 1X, 'TIME TAKEN TO REACH THIS ',
            *'POINT IS', E10. 3, ' SECS. ')
             WRITE(3, 110)XA, SIG3H, SIG3V, TA
      110    FORMAT(1H0, 'TRANSITION POINT TO PASSIVE DIFFUSION IS AT', E10. 3,
            *' METRES'/' VIRTUAL SOURCE HORIZONTAL AND VERTICAL STANDARD '
            *'DEVIATIONS ARE', 2E10. 3, ' METRES RESPECTIVELY'/' TIME TAKEN TO ',
            *'REACH THIS POINT IS', E10. 3, ' SECS. ')
      27     CONTINUE
      C
             WRITE(3, 100)
      100    FORMAT(1H0, 'HAZARD AREAS'/6(2H**)/
            *' APPROXIMATE REGION AFFECTED TO GREATER THAN ',
            *'GIVEN HAZARD LEVEL')
             IF(NTYPE. EQ. 2)WRITE(3, 117)
      117    FORMAT(1H , 'N. B. THESE VALUES MAY UNDERESTIMATE SIGNIFICANTLY',
            *' THE HAZARD REGION FOR FLAMMABLE GASES - FOR MORE ACCURATE',
            */, 2X, 'RESULTS USE THE ''RANGE'' CARD')
      C        DO 9 K=1, NHAZ
      C        CALL AREA(ABY, SHINT, SUMS, K, RANGE, RO)
      C        WRITE(3, 10)K, SUMS(K), RANGE(K)
      C10      FORMAT(1H , 'AT HAZARD LEVEL', I2, ' AREA IS', E10. 3, ' M**2 AND ',
      C       *'THE RANGE IS', E10. 3, ' M' / ' BOUNDARY POINTS AT EACH DOWNWIND ',
      C       *'GRID POINT ARE')
      C        WRITE(3, 11)(ABY(K, J), J=1, NINT)
      C11      FORMAT(8E12. 4)
      C9       CONTINUE
      C
      C
             WRITE(3, 111)
      111    FORMAT(1H0, 'CLOUD PARAMETERS'/8(2H**)/
            *1X, 'THE CONCENTRATION GIVEN IN THIS TABLE IS THE EQUIVALENT ',
            *'CENTRE LINE CONCENTRATION OF A GAUSSIAN DISTRIBUTION ',
            */, 1X, 'WITH 10( CONTOURS AT THE CLOUD RADII', /, /,
            *'  POSITION   STAGE    HEIGHT      RADIUS   CONCENT'
            *'RATION TIME TO PASS  CLOUD', 5X, 'TOTAL TIME'/'  (METRES)'11X,
            *'(METRES)', 4X, '(METRES)', 5X, 'KG/M**3', 6X, 'BY(MIN)', 4X, 'VEL(M/S)',
            *5X, '(SECS)')
             WRITE(3, 12)(XGRID(J), NST(J), HEIGHT(J), RADIUS(J), CONC(J), TAU(J),
            *UVEL(J), TCEN(J), J=1, NINT)
      12     FORMAT(E12. 4, I5, E14. 4, 5E12. 4)
      C
             IF(NHEAT. NE. 0. OR. NENT. NE. 0)WRITE(3, 22)
      20     FORMAT(1H0, '  POSITION        TEMP         DENSITY   DELTA RHO     HEAT
            * RATE   AIRMASS    ENTRAINMENT RICHARDSON'/'    METRES          DEGK
            *       KG/M**3     KG/M**3          J/SEC        KG           VELOCITY
            * NUMBER')
             IF(NHEAT. NE. 0. OR. NENT. NE. 0)WRITE(3, 20)
      22     FORMAT(1H0, 'IN THE FOLLOWING TABLE ALL VALUES REFER TO ',
            *'CONDITIONS WITHIN THE CLOUD. ', /, 1X, 'THE HEAT RATE IS THAT ',
            *'DUE TO HEATING FROM THE GROUND. ', /, 1X, 'AIRMASS IS THE MASS ',
      *'OF AIR WITHIN THE CLOUD'/, 1X, 'THE ENTRAINMENT VELOCITY IS ',
      *'THAT DUE TO ENTRAINMENT OVER THE UPPER SURFACE OF ',
      *'THE CLOUD')
        IF(NHEAT. NE. 0. OR. NENT. NE. 0. )WRITE(3, 21)(XGRID(J), TEK(J), ROA(J),
      *DELRHO(J), HRATE(J), AIRM(J), VELRAT(J), RICH(J), J=1, JGR)
 21     FORMAT(8E12. 4)
 C
 C        IF(NRANGE. NE. 0)CALL XAREA
 C        IF(NFN. EQ. 1)CALL CASNO(NWRITE)
 1042   FORMAT(1H0, ' ', /, ' ', /, ' ')
 C
        GO TO 113
 112    CONTINUE
        WRITE(3, 114)XK
 114    FORMAT(1H0, 'THE CLOUD HEIGHT AT'E10. 3,
      *' METRES DOWNWIND IS LESS THAN TWICE ',
      *'THE ROUGHNESS LENGTH'/, 1X, 'THE MODEL IS NOT VALID IN THIS ',
      *'SITUATION - NO FURTHER CALCULATIONS WILL BE PERFORMED ',
      *'WITH THE CURRENT SET OF DATA'/, 1X, 'RE-EXAMINE THE ',
      *'VALIDITY OF ALL PARAMETERS')
        IF(NFN. EQ. 1)WRITE(3, 115)
 115    FORMAT(1H , 'N. B. THE PROBABILITY OF THIS CASE OCCURRING',
      *' WILL NOT BE CONSIDERED IN THE P-N CALCULATION')
 113    CONTINUE
 97     CONTINUE
 C
 98     CONTINUE
 C        IF(NTYPE. EQ. 1. AND. NFN. NE. 0. )CALL ORDER
 C
        READ(6, 19)ABC
 19     FORMAT(A4)
        IF(ABC. EQ. EN)GO TO 778
        NCONT=1
        WRITE(3, 1042)
        CALL READIN(NCONT)
        GO TO 314
 778    CONTINUE
        STOP
        END
      SUBROUTINE HSTAG2(RAD,NSTAGE,HALFHT)
C     **********************************
C
      DIMENSION Y(3),W(15),DE(3),URAT(6),RRAT(6)
      INTEGER A,ZON,WIND,PR,CAT
      REAL MASS
C
      COMMON/BAT/SIGTH,SIGTV,SIG3H,SIG3V,CAY,TEMP
      COMMON/AAA/XS,XT,HT,XA,POPDIS(20,20),TX,A,J,XGRID(80),SHINT,NINT
      COMMON/BBB/ZO,ZON,WIND,MASS,PI,UZC,RO,HO,VO,G,RHO,RHOA,VEL(4,6),
     *UZM,UAV,USTAR,XK,XL
      COMMON/HEET/ALPH,CAIR,CGAS,TAIR,RHOGAS,TGROUND(6,4),ALSTAR,ALPI
      COMMON/CCC/CAS(3,12,4,6),P(12,4,6),MNO,CAT,ZM,TT,NST(50),TCEN(50)
      COMMON/EEE/HEIGHT(50),RADIUS(50),UVEL(50),TAU(50),CONC(50)
      COMMON/FFF/TA,TR,NVEL(6),NPOINT,NSEC,HTP,ALIM,NG
      COMMON/EXTRA/AMASS,ARE,NFN,NHEAT,TEK(80),ROA(80),HRATE(80),CMASS,
     *NRANGE,DELRHO(80),AIRM(80),VELRAT(80),RICH(80),NENT
      COMMON/GGG/NHAZ,NTYPE,NTIME(3),TOXIC(50,3),TEXP(50,3),HLEV(3),
     *TAW,EKONK,PR(3)
      COMMON/XYZ/NWRITE
C
      DATA URAT,RRAT/3.,3.,2.4,2.4,1.6,1.6,0.22,0.16,0.11,
     *0.09,0.06,0.04/
C
C     SUBROUTINE WHICH ALLOWS FOR ENTRAINMENT OF AIR AND CLOUD HEATING
C
C     URAT IS THE RATIO OF U1 TO USTAR(GERMELES AND DRAKE)
C     RRAT IS THE COEFFICIENT IN THE PARAMETERIZATION OF THE RATE
C     OF CHANGE OF SIGMA Y (CSTAR)
C
      N4=0
      NH=0
      JG=1
      NY=0
      IF(NHEAT.EQ.0) ALPH=0.
      Y(1)=RAD
      Y(2)=TEMP
      Y(3)=CMASS
C     RADIUS**2,TEMPERATURE AND MASS OF AIR ARE INDEPENDENT VARIABLES
      TIM=TR
      DT=TT-TR
    6 CALL HAIR(Y,DE,W,DT,TIM,3,JG)
      GO TO (1,2,3,2),JG
    1 WRITE(3,5)
    5 FORMAT(1H0,'FAILURE IN HAIR')
      RETURN
    2 CMASS=Y(3)
      RHO=(MASS+CMASS)*TAIR
      RHO=RHO/(CMASS/RHOA+MASS/RHOGAS)/Y(2)
C     RHO IS THE DENSITY OF THE CLOUD
      VT=(MASS+CMASS)/RHO
C     VT IS THE VOLUME OF THE CLOUD
      DEL=RHO-RHOA
      IF(DEL.LE.ALIM)GO TO 28
C
C     FIRST DIFFERENTIAL EQUATION-RADIUS**2
      DR=SQRT(Y(1))*RRAT(A)*UZC*4.28
```

```
        D1=2.*CAY*SQRT(G*DEL*VT/PI/RHOA)
        IF(DR.GT.D1)N4=1
C       TEST WHETHER OR NOT INCREASE IN RADIUS
C       DUE TO GRAVITATIONAL EFFECTS IS GREATER
C       THAN INCREASE DUE TO ATMOSPHERIC TURBULENCE ALONE
C
C       THIRD DIFFERENTIAL EQUATION-MASS OF AIR
C       DEFINITION OF ENTRAINMENT CRITERION
        IF(NENT.EQ.0)GO TO 25
        GO TO (21,22,23,24,25),NENT
 21     CONTINUE
C       COX AND ROE CRITERION
        HT=VT/PI/Y(1)
C       HT IS HEIGHT OF PLUME
        U1=URAT(A)*0.1*UZM
C       LONGITUDINAL ENTRAINMENT CRITERION
        EL=5.888*HT**0.48
C       TURBULENCE LENGTH SCALE
        RI=G*EL*DEL/U1/U1/RHOA
C       RICHARDSON NUMBER
        UE=ALPI*U1/RI
        IF(UE.GT.U1) UE=U1
C       ENTRAINMENT VELOCITY
        DEDGE=D1*HT*PI*ALSTAR*RHOA
C       EDGE ENTRAINMENT
        GO TO 26
 22     CONTINUE
 23     CONTINUE
 24     CONTINUE
 25     CONTINUE
        RI=0.
        UE=0.
        DEDGE=0.
C       NO ENTRAINMENT
 26     CONTINUE
        D3=RHOA*PI*Y(1)*UE+DEDGE
C
C       SECOND DIFFERENTIAL EQUATION-TEMPERATURE
        DFT=TGROUND(CAT,MNO)-Y(2)
        IF(DFT.LT.0.)DFT=0.
        DQ=ALPH*PI*Y(1)*DFT**1.3333
        DAT=TAIR-Y(2)
        D2=DQ+D3*CAIR*DAT
        D2=D2/(CMASS*CAIR+MASS*CGAS)
        IF(JQ.EQ.3)GO TO 7
        IF(JQ.EQ.4)GO TO 4
        DE(1)=D1
        DE(2)=D2
        DE(3)=D3
        GO TO 6
 4      Y(1)=DE(1)+DT*D1
        Y(2)=DE(2)+DT*D2
        Y(3)=DE(3)+DT*D3
        GO TO 6
 3      RAD=Y(1)
        TEMP=Y(2)
        CMASS=Y(3)
```

```
    7 RADIUS(J)=SQRT(RAD)
      ROA(J)=RHO
      TEK(J)=TEMP
      HRATE(J)=DG
      DELRHO(J)=RHO-RHOA
      AIRM(J)=CMASS
      VELRAT(J)=UE
      RICH(J)=RI
      HEIGHT(J)=VT/PI/RAD
      SIGMAZ=HEIGHT(J)/2.14
      SIGMAR=RADIUS(J)/2.14
      HALFHT=HEIGHT(J)/2.
      IF(HALFHT.LE.ZO)RETURN
      UZC=USTAR*ALOG(HALFHT/ZO)/0.4
      IF(J.EQ.NINT)GO TO 17
      UVEL(J+1)=UZC
   17 CONTINUE
      TX=2.*RADIUS(J)/UZC/60.
      TAU(J)=TX
      CONC(J)=MASS/PI/SIGMAR/SIGMAZ/UZC
      IF(NTYPE.EQ.1)CONC(J)=CONC(J)/TX/60.
      IF(NTYPE.EQ.2)CONC(J)=CONC(J)*UZC/SIGMAR/SQRT(2*PI)
C     TESTS FOR TRANSITION TO STAGE 4
      IF(NENT.EQ.0)GO TO 27
C     NENT IS 0,NO ENTRAINMENT
      RAT=UE/U1
      IF(RAT.LT.1.OR.N4.EQ.0) RETURN
C     THIS CRITERION STILL APPROXIMATE
      NY=1
      GO TO 28
   27 DEL=RHO-RHOA
      IF(DEL.GT.ALIM)RETURN
   28 CONTINUE
C     STAGE 4
      TA=TR
      NSTAGE=4
      IF(J.EQ.1)GO TO 8
      XA=EXP((J-2)*SHINT)
      SIG3V=HEIGHT(J-1)/2.14
      SIG3H=RADIUS(J-1)/2.14
      GO TO 9
    8 CONTINUE
      XA=0.
      SIG3V=H0/2.14
      SIG3H=R0/2.14
    9 CONTINUE
      IF(NY.EQ.1.AND.NWRITE.EQ.1)WRITE(3,19)
      IF(NY.EQ.1.AND.J.EQ.1)WRITE(3,19)
   19 FORMAT(1H0,'SLUMPING TERMINATED BECAUSE ENTRAINMENT VELOCITY IS ',
     *'GREATER THAN LONGITUDINAL TURBULENCE VELOCITY'/,1X,
     *'AND RATE OF INCREASE IN RADIUS DUE TO GRAVITATIONAL EFFECTS',
     *' IS LESS THAN THAT EXPECTED FROM ATMOSPHERIC TURBULENCE')
      IF(NY.EQ.0.AND.NWRITE.EQ.1)WRITE(3,20)
      IF(NY.EQ.0.AND.J.EQ.1)WRITE(3,20)
   20 FORMAT(1H0,'SLUMPING TERMINATED BY DISAPPEARANCE OF DENSITY DIFFER
     *ENCE')
      IF(J.EQ.1)WRITE(3,29)
```

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HSTAG2                                                          25-May-1983 17:0
                                                                24-May-1983 09:4

0129     29     FORMAT(1H , 'AT A POINT LESS THAN 1 METRE DOWNWIND-TREAT ',
               *'ANY RESULTS WITH CAUTION')
0130            RETURN
0131            END



PROGRAM SECTIONS

    Name                                          Bytes   Attributes

  0 $CODE                                          1689   PIC CON REL LCL   SHR   EXE   RI
  1 $PDATA                                          391   PIC CON REL LCL   SHR NOEXE   RI
  2 $LOCAL                                          256   PIC CON REL LCL NOSHR NOEXE   RI
  3 BAT                                              24   PIC OVR REL GBL   SHR NOEXE   RI
  4 AAA                                            1956   PIC OVR REL GBL   SHR NOEXE   RI
  5 BBB                                             164   PIC OVR REL GBL   SHR NOEXE   RI
  6 HEET                                            124   PIC OVR REL GBL   SHR NOEXE   RI
  7 CCC                                            5024   PIC OVR REL GBL   SHR NOEXE   RI
  8 EEE                                            1000   PIC OVR REL GBL   SHR NOEXE   RI
  9 FFF                                              52   PIC OVR REL GBL   SHR NOEXE   RI
 10 EXTRA                                          2268   PIC OVR REL GBL   SHR NOEXE   RI
 11 GGG                                            1252   PIC OVR REL GBL   SHR NOEXE   RI
 12 XYZ                                               4   PIC OVR REL GBL   SHR NOEXE   RI

ENTRY POINTS

    Address   Type  Name

  0-00000000        HSTAG2


VARIABLES

    Address   Type  Name                 Address   Type  Name                Address   Ty

  4-00000654  I*4   A                 9-0000002C  R*4   ALIM             6-00000000  F
  6-00000074  R*4   ALSTAR           10-00000000  R*4   AMASS           10-00000004  F
  7-00001204  I*4   CAT               3-00000010  R*4   CAY              6-00000008  F
  2-000000A8  R*4   D1                2-000000D0  R*4   D2               2-000000C0  F
  2-000000BC  R*4   DEDGE             2-000000A0  R*4   DEL              2-000000C4  F
  2-000000A4  R*4   DR                2-00000098  R*4   DT              11-000004D4  F
  5-00000024  R*4   G                 5-0000001C  R*4   HO              AP-0000000C@ F
  9-00000028  R*4   HTP               4-00000658  I*4   J                2-0000008C  I
  7-00001200  I*4   MNO               2-00000084  I*4   N4              10-000008D8  I
  2-00000088  I*4   NH               11-00000000  I*4   NHAZ            10-0000000C  I
  9-00000020  I*4   NPOINT            9-00000030  I*4   NG              10-000003D4  I
 AP-00000008@ I*4   NSTAGE           11-00000004  I*4   NTYPE           12-00000000  I
  5-00000010  R*4   PI                5-00000018  R*4   RO              AP-00000004@ F
  5-00000028  R*4   RHO               5-0000002C  R*4   RHOA             6-00000010  F
  4-0000079C  R*4   SHINT             3-00000008  R*4   SIG3H            3-0000000C  F
  2-000000D4  R*4   SIGMAZ            3-00000000  R*4   SIGTH            3-00000004  F
  6-0000000C  R*4   TAIR             11-000004D0  R*4   TAW              3-00000014  F
  9-00000004  R*4   TR                7-0000120C  R*4   TT               4-00000650  F
  5-00000094  R*4   UAV               2-000000B8  R*4   UE               5-00000098  F
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                                                                  25-May-1983 17:04
                                                                  24-May-1983 09:52
              C
              C      INTEGRAL IS A SIMPSON'S RULE INTEGRATION
              C
 0001                REAL*8 FUNCTION INTEGRAL(P)
 0002                IMPLICIT REAL*8 (A-H,O-Z)
 0003                DIMENSION FUNC(100)
 0004                DATA PI/3.14159265/
              C       THIS IS BASED ON e-(10**2/2) = - (INFINITY) ON A GAUSSIAN CURVE
 0005                PX=-10.
 0006                RANGE=P-PX
 0007                DX=RANGE/99.
 0008                DO 10 I=1,100
 0009                FUNC(I)=EXP(-0.5*PX*PX)
 0010                PX=PX+DP
 0011           10   CONTINUE
 0012                M=100
 0013                CALL FSIMP(FUNC,RANGE,M,RES)
 0014                INTEGRAL=RES/SQRT(2.*PI)
 0015                RETURN
 0016                END


PROGRAM SECTIONS

    Name                                      Bytes   Attributes

  0 $CODE                                       114   PIC CON REL LCL   SHR    EXE    RD
  2 $LOCAL                                      884   PIC CON REL LCL NOSHR NOEXE   RD

ENTRY POINTS

    Address   Type  Name

  0-00000000  R*8   INTEGRAL

VARIABLES

    Address   Type  Name                  Address   Type  Name                  Address   Ty

  2-00000348  R*8   DP                  2-00000340  R*8   DX                  2-00000358  I
 AP-00000004@ R*8   P                   2-00000328  R*8   PI                  2-00000330  R
  2-00000350  R*8   RES

ARRAYS

    Address   Type  Name                 Bytes  Dimensions

  2-00000000  R*8   FUNC                   800  (100)
```

```
      C
      C       CALCULATE INDOOR/OUTDOOR ATTENUATION EFFECT
      C
             SUBROUTINE INDOOR
             IMPLICIT REAL*8 (A-H,O-Z)
             INCLUDE 'PUFF.CMN'
    * C
    * C       PUFF CONTAINS THE PUFF MODEL SPECIFIC SOURCE ARRAYS
    * C
    *        COMMON /PUFF/ PUFFT(100,100),PUFFQ(100,100),TAUB,TAU
             INCLUDE 'PARA.CMN'
    * C       COMMON PARA IS THE MAIN PARAMETER BLOCK
    * C       -CGX,CGY ARE THE LOCATIONS OF THE CG OF
    * C        THE AREA BEING REPRESENTED
    * C       -POP IS THE POPULATION REPRESENTED AT THE CG (IN # OF PEOPLE)
    * C       -AREA IS THE AREA OF THE REPRESENTED ELEMENT OF TERRAIN(KM**2)
    * C       -ELEV IS ELEVATION OF AREA
    * C       -H IS THE EFFECTIVE RELEASE HEIGHT
    * C       -XCORD,YCORD ARE THE COMPONENTS FOR THE CONCENTRATION CALC
    * C
    *        COMMON /PARA/ CGX(1000),CGY(1000),AREA(1000),POP(1000)
    *       Z,ELEV(1000),NP,H(1000),CONC(1000),XCORD(1000),YCORD(1000)
             X=LOG(TAUB/TAU)/(1./TAU-1./TAUB)
             X=1./(TAUB/TAU-1.)*EXP(-1.*X/TAUB)-EXP(-1.*X/TAU)
             DO 10 I=1,NP
             CONC(I)=CONC(I)*X
          10 CONTINUE
             RETURN
             END
      C
      C       CASE SPECIFIC INPUT DATA ROUTINE
      C
              SUBROUTINE INPUTC(ICASE)
              IMPLICIT REAL*8 (A-H,O-Z)
              INCLUDE 'DISPD.CMN'
    * C       FACTORS FOR DISPERSION COEFFICIENTS
    * C
    * C    AA1,AA2,BB1,BB2,CC3 ARE FUNCTION OF WEATHER CLASS
    * C    CC1,CC2,DD1,DD2,     ARE FUNCTIONS OF ROUGHNESS
    * C
    *         COMMON/DISPD/ AA1(6),AA2(6),BB1(6),BB2(6),CC1(6)
    *        1,CC2(6),CC3(6),DD1(6),DD2(6),ZO(6)
              INCLUDE 'OPTIONS.CMN'
    * C
    * C       OPTIONS CONTAIN ALL OPTIONS REQUIRED FOR EXECUTION
    * C
    *         COMMON /OPTIONS/ IOPTION(11),IRUNCODE
    * C       IOPTION IS DEFINED AS FOLLOWS :
    * C                     IOPTION(1)  : PLUME MODEL=1; PUFF .NE.1; IN/OUTDOOR=3
    * C                     IOPTION(2)  : SIGMA Y,Z OPTIONS 1,2,OR 3
    * C                     IOPTION(3)  : WEATHER CLASS (1=A,2=B,...6=F)
    * C                     IOPTION(4)  : TERRAIN ROUGHNESS(1,2,...6)
    * C                     IOPTION(5)  : GRAVITY EFFECT OPTION (1=INCLUDE)
    * C                     IOPTION(6)  : BUILDING EFFECT OPTION (1=INCLUDE)
    * C                     IOPTION(7)  : TERRAIN MODIFICATION (1=INCLUDE)
    * C                     IOPTION(8)  : TRAPPING OPTION (1=INCLUDE)
    * C                     IOPTION(9)  : LAKE BREEZE EFFECT (1=INCLUDE)
    * C                     IOPTION(10) : DEBUGGING SWITCH 1= ADDITIONAL OUTPUT
    * C                                                    2= TERRAIN PLOT PRODUCED
    * C                     IOPTION(11) : RELEASE TYPE 1=PASSIVE
    * C                                                2=VERTICAL JET
    * C                                                3=FLARE
    * C                                                4=HEAVIER THAN AIR
              INCLUDE 'LINKUP.CMN'
    *         COMMON /LINKUP/ PERC(10),FIXJ(1000,10),PROB(10),
    *        ZCLT(10,10),TCLT(10,10),PK(10),PJGRID(10),PJ(10),
    *        ZGRIDFAT(1000,10),ZNU(10),PROBJ(1000),J1
    * C
    * C        CONCENTRATION LETHAL DOSE = CLT
    * C        EXPOSURE TIMES FOR CLT    = TCLT
    * C
              DATA AA1/0.112,0.130,0.112,0.098,0.0609,0.0638/
              DATA AA2/5.38E-4,6.52E-4,9.05E-4,1.35E-3,1.96E-3,1.36E-3/
              DATA BB1/1.06,0.95,0.92,0.889,0.895,0.783/
              DATA BB2/0.815,0.750,0.718,0.688,0.684,0.672/
              DATA CC1/1.56,2.02,2.72,5.16,7.37,11.7/
              DATA CC2/6.25E-4,7.76E-4,0.0,18.6,4.29E+3,4.59E+4/
              DATA CC3/0.22,0.16,0.11,0.08,0.06,0.04/
              DATA DD1/0.048,0.027,0.0,-0.098,-0.096,-0.128/
              DATA DD2/0.45,0.37,0.0,-0.225,-0.60,-0.78/
              DATA ZO/.01,.04,.10,.40,1.00,4.00/
              READ(2,10,ERR=20,END=20) ICASE,P
       10     FORMAT(I4,F10.0)
              IF(ICASE.GT.1000) THEN
                      WRITE(1,30)
                      WRITE(3,30)
```

```
0024       30           FORMAT(' ** WARNING ONLY 1ST 1000 CASES
              Z         ARE CONSIDERED')
0025                    ICASE=0
0026                    ENDIF
0027             IF(ICASE.GT.0) PROBJ(ICASE)=P
0028             RETURN
0029       20    CONTINUE
0030             WRITE(1,21)
0031             WRITE(3,21)
0032       21    FORMAT('***ERROR FOUND IN DATA FILE WHILE READING THE',
              Z' CASE SPECIFIC DATA')
0033             STOP ' CHECK DATA FILE AND CORRECT'
0034             END


PROGRAM SECTIONS

   Name                                     Bytes  Attributes

 0 $CODE                                      186  PIC CON REL LCL   SHR   EXE   RD
 1 $PDATA                                     161  PIC CON REL LCL   SHR NOEXE   RD
 2 $LOCAL                                      16  PIC CON REL LCL NOSHR NOEXE   RD
 3 DISPD                                      480  PIC OVR REL GBL   SHR NOEXE   RD
 4 OPTIONS                                     48  PIC OVR REL GBL   SHR NOEXE   RD
 5 LINKUP                                  170084  PIC OVR REL GBL   SHR NOEXE   RD


ENTRY POINTS

   Address   Type  Name

 0-00000000        INPUTC


VARIABLES

   Address   Type  Name                 Address   Type  Name             Address   Typ

AP-00000004@ I*4   ICASE              4-0000002C  I*4   IRUNCODE       5-00029860  I*


ARRAYS

   Address   Type  Name                          Bytes  Dimensions

 3-00000000  R*8   AA1                              48  (6)
 3-00000030  R*8   AA2                              48  (6)
 3-00000060  R*8   BB1                              48  (6)
 3-00000090  R*8   BB2                              48  (6)
 3-000000C0  R*8   CC1                              48  (6)
 3-000000F0  R*8   CC2                              48  (6)
 3-00000120  R*8   CC3                              48  (6)
 5-00013920  R*8   CLT                             800  (10, 10)
 3-00000150  R*8   DD1                              48  (6)
 3-00000180  R*8   DD2                              48  (6)
```

```
                                                     25-May-1983 17 05
                                                      2-May-1983 16 18
            SUBROUTINE INPUTP
            IMPLICIT REAL*8 (A-H,O-Z)
            INCLUDE 'RISKS.CMN'
*           COMMON /RISKS/V(10),FMAX(10),SPECA(10),SPECC(10),ZO(10),T(10),
*          ZS(10),XTT(10),FO(10),D(10),XS(10),BETA,PROBAB
            INCLUDE 'LINKUP.CMN'
*           COMMON /LINKUP/ PERC(10),FIXJ(1000,10),PROB(10),
*          ZCLT(10,10),TCLT(10,10),PK(10),PJGRID(10),PJ(10),
*          ZGRIDFAT(1000,10),ZNU(10),PROBJ(1000),J1
* C
* C          CONCENTRATION LETHAL DOSE = CLT
* C          EXPOSURE TIMES FOR CLT    = TCLT
* C
           READ(5,10) BETA,SPECC(1),SPECA(1),FMAX(1),S(1)
        10 FORMAT(5F10.0)
  C
  C          INPUT LETHAL THRESHOLD CONCENTRATION CURVES
  C
           DO 11 I=1,10
           READ(5,12) PERC(I)
        12 FORMAT(2F10.0)
           IF(PERC(I).LE.0.) GO TO 13
           DO 14 J=1,10
           READ(5,12) TCLT(I,J),CLT(I,J)
           IF(TCLT(I,J).LE.0.) GO TO 11
        14 CONTINUE
        11 CONTINUE
        13 CONTINUE
           READ(5,20) (PJ(I),I=1,10)
        20 FORMAT(10F10.0)
           DO 21 J=1,10
           IF(PJ(J).LE.0.) GO TO 22
        21 CONTINUE
        22 CONTINUE
           J1=J-1
           READ(5,20) (ZNU(I),I=1,10)
           RETURN
           END
```

25-May-1983 17:03:
25-May-1983 16:32:

```
           SUBROUTINE INPUTR
           IMPLICIT REAL*8 (A-H,O-Z)
           CHARACTER*80 TITLE
           INCLUDE 'OPTIONS.CMN'
* C
* C         OPTIONS CONTAIN ALL OPTIONS REQUIRED FOR EXECUTION
* C
*          COMMON /OPTIONS/ IOPTION(11),IRUNCODE
* C         IOPTION IS DEFINED AS FOLLOWS :
* C                      IOPTION(1)  : PLUME MODEL=1; PUFF .NE. 1; IN/OUTDOOR=3
* C                      IOPTION(2)  : SIGMA Y,Z OPTIONS 1,2,OR 3
* C                      IOPTION(3)  : WEATHER CLASS (1=A,2=B,...6=F)
* C                      IOPTION(4)  : TERRAIN ROUGHNESS(1,2,...6)
* C                      IOPTION(5)  : GRAVITY EFFECT OPTION (1=INCLUDE)
* C                      IOPTION(6)  : BUILDING EFFECT OPTION (1=INCLUDE)
* C                      IOPTION(7)  : TERRAIN MODIFICATION (1=INCLUDE)
* C                      IOPTION(8)  : TRAPPING OPTION (1=INCLUDE)
* C                      IOPTION(9)  : LAKE BREEZE EFFECT (1=INCLUDE)
* C                      IOPTION(10) : DEBUGGING SWITCH 1= ADDITIONAL OUTPUT
* C                                                     2= TERRAIN PLOT PRODUCED
* C
* C                      IOPTION(11) : RELEASE TYPE 1=PASSIVE
* C                                                 2=VERTICAL JET
* C                                                 3=FLARE
* C                                                 4=HEAVIER THAN AIR
           INCLUDE 'PUFF.CMN'
* C
* C         PUFF CONTAINS THE PUFF MODEL SPECIFIC SOURCE ARRAYS
* C
*          COMMON /PUFF/ PUFFT(100,100),PUFFQ(100,100),TAUB,TAU
           INCLUDE 'ATMOS.CMN'
* C
* C        ATMOS CONTAINS ALL PERTINENT DATA FOR CONCENTRATION
* C        CALCULATIONS AND DETERMINATION OF SIGMA'S
* C
*          COMMON /ATMOS/ QRATE(100),USPEED,HEIGHT(100),SIGY,
*         ZSIGZ,SIGTHETA,SIGPHI,XT,RT,HT,C,AO,XLS(100),
*         ZELEVSOUR(100),XLID,WDIR,SX(100),SY(100),
*         ZILAKE,IWCLASS2,NSOURCE
           INCLUDE 'RELTYPE.CMN'
*          COMMON /RELTYPE/ DISCH(100),WO,SO2FLOW(100),DTHDZ,ALPHA,
*         ZU10,CFLARE,AMTEMP
           DATA PI/3.14159265/
           READ(2,10) IRUNCODE,TITLE
      10   FORMAT(I2,A80)
           READ(2,11,ERR=21,END=14) (IOPTION(I),I=1,11),
          ZXLID,WIND,USPEED,SIGTHETA,SIGPHI,
          ZXT,RT,HT,C,AO,IWCLASS2
      11   FORMAT(11I4,/,5F20.0,/,5F20.0,I4,5F20.0)
           DO 42 I=1,100
           READ(2,41) N,SX(I),SY(I),ELEVSOUR(I),HEIGHT(I),QRATE(I),
          ZXLS(I),DISCH(I),SO2FLOW(I)
      41   FORMAT(I4,8F20.0)
           IF(N.EQ.0) GO TO 43
      42   CONTINUE
      43   CONTINUE
           NSOURCE=I-1
           DO 45 J=1,100
      READ(2, 16, ERR=21, END=14) N
   16 FORMAT(I4)
      IF(N. EQ. 0) GO TO 46
      DO 12 I=1, 100
      READ(2, 13, ERR=21, END=14) PUFFT(J, I), PUFFQ(J, I)
   13 FORMAT(2F20. 0)
      IF(PUFFQ(J, I). EQ. 0. ) GO TO 15
   12 CONTINUE
   15 CONTINUE
   45 CONTINUE
   46 CONTINUE
      IF(IOPTION(1). NE. 1) NSOURCE=J-1
      READ(2, 13) TAU, TAUB
C
C      INPUT DIAGNOSTIC AND PROCESSING
C
      IF(USPEED. LT. 0. ) THEN
               WIND=WIND+180.
               USPEED=-1. *USPEED
               ENDIF
      IF(USPEED. LT. 0. 01) THEN
               WRITE(1, 17)
               WRITE(3, 17)
  17           FORMAT(' ***WIND SPEED INPUT AS LESS THAN 0. 01'
     Z         , ' M/SEC.  IT HAS BEEN SET TO 0. 01')
               USPEED=0. 01
               ENDIF
C
C      WIND IS INPUT IN TERMS OF THE DIRECTION (IN DEGREES)
C      FROM WHERE THE WIND IS FROM. WDIR IS THE DIRECTION
C      THE WIND IS GOING (IN RADIANS)
C
      WDIR=2. *PI*WIND/360. +PI
      IF(WDIR. GT. 2. *PI) WDIR=WDIR-2. *PI
      IF(XLID. LT. 0. ) STOP ' **ERROR LID HEIGHT SET AT LESS THAN 0. '
      IF(IOPTION(2). LT. 1. AND. IOPTION(2). GT. 3) THEN
                  WRITE(3, 22)
                  WRITE(1, 22)
  22              FORMAT(' ***WARNING -- CALCULATION OPTION FOR '
     Z            , 'DISPERSION COEFFICIENTS NOT SPECIFIED', /
     Z            , ' DEFAULT VALUE OF OPTION 1 IS USED')
                  IOPTION(2)=1
                  ENDIF
      IF(IOPTION(5). EQ. 1. AND. IOPTION(6). EQ. 1) THEN
                  WRITE(3, 23)
                  WRITE(1, 23)
  23              FORMAT(' ** WARNING-- BOTH GRAVITY AND BUILDING'
     Z            ' EFFECT ADJUSTMENTS HAVE BEEN SPECIFIED', /
     Z            ' DEFAULTING TO GRAVITY EFFECT ONLY')
                  ENDIF
      IF(IOPTION(5). NE. 1. AND. IOPTION(11). EQ. 4) THEN
                  WRITE(3, 53)
                  WRITE(1, 53)
  53              FORMAT(' **WARNING -- GRAVITY OPTION WAS NOT'
     Z            ' SELECTED WITH THE HEAVY GAS OPTION', /,
     Z            ' DEFAULTING TO IOPTION(5)=1 ******')
                  IOPTION(5)=1
```

```
                         ENDIF
         IF(IOPTION(8).EQ.1.AND.IOPTION(9).EQ.1) THEN
                         WRITE(3,24)
                         WRITE(1,24)
   24                    FORMAT(' **WARNING -- TRAPPING EFFECT IS NOT '
    Z                    'CALCULATED WITH THE LAKE BREEZE OPTION')
                         IOPTION(8)=0
                         ENDIF
         IF(IOPTION(9).EQ.1.AND.(IWCLASS2.LT.1.OR.IWCLASS2.GT.6))THEN
                         WRITE(3,25)
                         WRITE(1,25)
   25                    FORMAT(' **WARNING -- LAKEBREEZE OPTION SELECTED.',/
    Z                    ,' BUT NO VALUE OF THE INTERNAL STABILITY '
    Z                    ,'WAS SPECIFIED.',/
    Z                    ,' DEFAULT VALUE OF 3 USED ')
                         IWCLASS2=3
                         ENDIF
         IF(IOPTION(1).EQ.3.AND.IOPTION(9).EQ.1) THEN
                         WRITE(1,40)
                         WRITE(3,40)
   40                    FORMAT(' ** WARNING - INDOOR/OUTDOOR ATTENUATION
    Z                    EFFECT IS NOT CALCULATED WHEN CALCULATING PUFF
    Z                    MODEL TERMS OF THE LAKEBREEZE EFFECT')
                         ENDIF
C
C        OUTPUT
C
         WRITE(3,30) TITLE
   30    FORMAT('1',//,25X,'P R O G R A M   G A S P R O B',
    Z/,25X,7('- '),2X,7('- '),///
    Z' RUN TITLE :  ',A80,/////
    Z,5X,'RUN SPECIFICATIONS :',/)
         WRITE(3,31) USPEED,WIND,XLID,IWCLASS2,TAU,TAUB,
    ZSIGTHETA,SIGPHI,XT,RT,HT,C,AO,IOPTION
   31    FORMAT(' REFERENCE WIND SPEED (10. METRE) :  ',12X,G12.5,' M/SEC'
    Z,/,' WIND DIRECTION (FROM) :  ',11X,G12.5,' DEGREES',//,
    Z' LID HEIGHT (OPTIONAL) :  ',10X,G12.5,' METRES',/
    Z' STABILITY WITHIN THE TIBL (OPTIONAL) :  ',I2,/
    Z' TIME CONSTANT OF BLOWDOWN :  ',G12.5,/
    Z' TIME CONSTANT OF BUILDINGS :  ',G12.5,/
    Z' ATMOSPHERIC PARAMETERS SIGTHETA,SIGPHI,XT,RT,HT,C,AO :  ',
    Z/,5X,7(G11.4,1X),//,' METHOD OF CALCULATION OPTIONS :  ',11I2)
         IF(IOPTION(1).NE.1) THEN
                         WRITE(3,35)
   35                    FORMAT(//' PUFF MODEL SPECIFICATIONS',//)
                         DO 37 J=1,NSOURCE
                         WRITE(3,36) J
   36                    FORMAT(/,' SOURCE NUMBER :  ',I4,//,
    Z                    9X,'TIME',9X,'SIZE OF PUFF',/,
    Z                    9X,'SECS',9X,'    UNITS     ',/)
                         DO 33 I=1,100
                         IF(PUFFQ(J,I).LE.0.) GO TO 34
                         WRITE(3,32) PUFFT(J,I),PUFFQ(J,I)
   32                    FORMAT(7X,2(G12.5,4X))
   33                    CONTINUE
   34                    CONTINUE
   37                    CONTINUE
```

```
                          ELSE
      C               PLUME MODEL
                              WRITE(3,38)
          38                  FORMAT(/,' PLUME SOURCE DATA',//,
             Z                ' ELEVATION        HEIGHT        X          ',
             Z                '    Y           RATE OF     DISTANCE       ',
             Z                'DISCHARGE        SO2',/' AT SOURCE      OF ',
             Z                'SOURCE    COORD         COORD          RELEASE',
             Z                '      FROM LAKE     DIAMETER    FLOW RATE'/)
                              DO 39 IS=1,NSOURCE
                              WRITE(3,50) ELEVSOUR(IS),HEIGHT(IS),SX(IS),SY(IS),
             Z                QRATE(IS),XLS(IS),DISCH(IS),SO2FLOW(IS)
          50                  FORMAT(8(G12.5,1X))
          39                  CONTINUE
                              ENDIF
                RETURN
          14    CONTINUE
                STOP 'ERROR IN INPUT SPECIFICATION OF PUFF MODEL SOURCE'
          21    CONTINUE
                STOP 'ERROR IN FORMAT OF DATA FILE GASPROB.DAT'
                END



PROGRAM SECTIONS

    Name                                        Bytes   Attributes

  0 $CODE                                        1968   PIC CON REL LCL   SHR   EXE   R
  1 $PDATA                                       1816   PIC CON REL LCL   SHR NOEXE   R
  2 $LOCAL                                        184   PIC CON REL LCL NOSHR NOEXE   R
  3 OPTIONS                                        48   PIC OVR REL GBL   SHR NOEXE   R
  4 PUFF                                       160016   PIC OVR REL GBL   SHR NOEXE   R
  5 ATMOS                                        4908   PIC OVR REL GBL   SHR NOEXE   R
  6 RELTYPE                                      1648   PIC OVR REL GBL   SHR NOEXE   R

ENTRY POINTS

    Address   Type  Name

  0-00000000        INPUTR

VARIABLES

    Address   Type  Name                   Address   Type  Name                  Address   T

  5-00000688  R*8   A0                   6-00000650  R*8   ALPHA               6-00000668
  6-00000660  R*8   CFLARE               6-00000648  R*8   DTHDZ               5-00000678
  5-00001320  I*4   ILAKE                3-0000002C  I*4   IRUNCODE            2-0000006C
  2-00000068  I*4   J                    2-00000064  I*4   N                   5-00001328
  5-00000670  R*8   RT                   5-00000660  R*8   SIGPHI              5-00000658
  5-00000650  R*8   SIGZ                 4-00027108  R*8   TAU                 4-00027100
  6-00000658  R*8   U10                  5-00000320  R*8   USPEED              6-00000320
  2-00000058  R*8   WIND                 5-00000CD0  R*8   XLID                5-00000668
```

```
          SUBROUTINE INPUTT
          IMPLICIT REAL*8 (A-H,O-Z)
          CHARACTER*70 LINE
          INCLUDE 'OLDD.CMN'
*         COMMON /OLDD/ NELM(1000,4),X(1000),Y(1000)
*        1,IDIV(1000),NN,NC,POPDENS(1000),ELEVOLD(1000),IPOP
* C
* C        NN=NUMBER OF ELEMENTS IN ORIGINAL DATA
* C        NC=NUMBER OF COORDINATES IN ORIGINAL DATA
* C
*
          ITMAX=0
          IL=1
          READ(4,102) IPOP
    102   FORMAT(I4)
          DO 1 I=1,1000
          READ(4,100,END=300,ERR=300) K,(NELM(I,J),J=1,4),IDIV(I),
         ZPOPDENS(I),ELEVOLD(I)
     100 FORMAT(6I6,2F20.0)
          IF(K.EQ.0) GO TO 2
          IL=IL+1
          IF(IDIV(I).LE.0) IDIV(I)=1
          DO 3 J=1,4
          IF(NELM(I,J).GT.NC) NC=NELM(I,J)
       3 CONTINUE
       1 CONTINUE
       2 NN=I-1
          DO 4 I=1,NC
          READ(4,101,ERR=300)K, X(K),Y(K)
     101 FORMAT(I5,2F20.0)
          X(K)=X(K)*1000.
          Y(K)=Y(K)*1000.
          IF(K.GT.1000) STOP 'ERROR - MORE THAN 1000 COORDINATES'
          IL=IL+1
       4 CONTINUE
  C
  C  CALL DIVIS TO GENERATE NEW ELEMENTS
  C
          CALL DIVIS
          CLOSE(UNIT=4)
          RETURN
  C
     300 CONTINUE
          WRITE(1,200) IL
     200 FORMAT('   ERROR IN INPUT FOR AREA DEFINITION AT LINE'I4,/,
         Z'   OF TERRAIN SPECIFICATION FILE TERRAIN.DAT'/)
          BACKSPACE 4
          READ(4,104) LINE
     104 FORMAT(A70)
          TYPE 105,LINE
     105 FORMAT(2X,A70)
          STOP'  CORRECT ERROR'
          END
```

```
        C
        C       - OPTIONAL LAKEBREEZE EFFECT
        C       - CALCULATION IS ACCORDING TO LYON'S 3-STAGE MODEL
        C
                SUBROUTINE LAKE(ISOURCE)
                IMPLICIT REAL*8 (A-H,O-Z)
                REAL*8 INTEGRAL
                DIMENSION TPEAK(100)
                INCLUDE 'ATMOS.CMN'
      * C
      * C       ATMOS CONTAINS ALL PERTINENT DATA FOR CONCENTRATION
      * C       CALCULATIONS AND DETERMINATION OF SIGMA'S
      * C
      *         COMMON /ATMOS/ GRATE(100),USPEED,HEIGHT(100),SIGY,
      *        ZSIGZ,SIGTHETA,SIGPHI,XT,RT,HT,C,AO,XLS(100),
      *        ZELEVSOUR(100),XLID,WDIR,SX(100),SY(100),
      *        ZILAKE,IWCLASS2,NSOURCE
                INCLUDE 'PARA.CMN'
      * C        COMMON PARA IS THE MAIN PARAMETER BLOCK
      * C        -CGX,CGY ARE THE LOCATIONS OF THE CG OF
      * C         THE AREA BEING REPRESENTED
      * C        -POP IS THE POPULATION REPRESENTED AT THE CG (IN # OF PEOPLE)
      * C        -AREA IS THE AREA OF THE REPRESENTED ELEMENT OF TERRAIN(KM**2)
      * C        -ELEV IS ELEVATION OF AREA
      * C        -H IS THE EFFECTIVE RELEASE HEIGHT
      * C        -XCORD,YCORD ARE THE COMPONENTS FOR THE CONCENTRATION CALC
      * C
      *         COMMON /PARA/ CGX(1000),CGY(1000),AREA(1000),POP(1000)
      *        Z,ELEV(1000),NP,H(1000),CONC(1000),XCORD(1000),YCORD(1000)
                INCLUDE 'OPTIONS.CMN'
      * C
      * C        OPTIONS CONTAIN ALL OPTIONS REQUIRED FOR EXECUTION
      * C
      *         COMMON /OPTIONS/ IOPTION(11),IRUNCODE
      * C        IOPTION IS DEFINED AS FOLLOWS :
      * C                       IOPTION(1)  : PLUME MODEL=1, PUFF .NE. 1, IN/OUTDOOR=3
      * C                       IOPTION(2)  : SIGMA Y,Z OPTIONS 1,2,OR 3
      * C                       IOPTION(3)  : WEATHER CLASS (1=A,2=B,...6=F)
      * C                       IOPTION(4)  : TERRAIN ROUGHNESS(1,2,...6)
      * C                       IOPTION(5)  : GRAVITY EFFECT OPTION (1=INCLUDE)
      * C                       IOPTION(6)  : BUILDING EFFECT OPTION (1=INCLUDE)
      * C                       IOPTION(7)  : TERRAIN MODIFICATION (1=INCLUDE)
      * C                       IOPTION(8)  : TRAPPING OPTION (1=INCLUDE)
      * C                       IOPTION(9)  : LAKE BREEZE EFFECT (1=INCLUDE)
      * C                       IOPTION(10) : DEBUGGING SWITCH 1= ADDITIONAL OUTPUT
      * C                                                      2= TERRAIN PLOT PRODUCED
      * C                       IOPTION(11) : RELEASE TYPE 1=PASSIVE
      * C                                                  2=VERTICAL JET
      * C                                                  3=FLARE
      * C                                                  4=HEAVIER THAN AIR
                INCLUDE 'PUFF.CMN'
      * C
      * C        PUFF CONTAINS THE PUFF MODEL SPECIFIC SOURCE ARRAYS
      * C
      *         COMMON /PUFF/ PUFFT(100,100),PUFFQ(100,100),TAUB,TAU
                DATA PI/3.14159265/
                DO 10 I=1,NP
      IF(XCORD(I).LE.0.) THEN
                  CONC(I)=0.
                  GO TO 10
                  ENDIF
C
C      CALCULATE XB & XE TO DETERMINE ZONE
C
      XIC=1.
      XBOUT=XBE(I,XIC)
      XIC=-1.
      XEOUT=XBE(I,XIC)
      IF(XCORD(I).GE.XBOUT) GO TO 22
C
C      ZONE 1
C
C
C      CACULATE SIGMA'S
C
      CALL SIG(XCORD(I),YCORD(I))
      IF(IOPTION(1).EQ.1) THEN
C         PLUME MODEL
                     CONC(I)=QRATE(ISOURCE)/PI/SIGY/SIGZ/USPEED
                     CONC(I)=CONC(I)*EXP(-0.5*(YCORD(I)/SIGY)**2)
                     CONC(I)=CONC(I)*EXP(-0.5*(H(I)/SIGZ)**2)
                  ELSE
C         PUFF MODEL
C       THIS SECTION TAKEN FROM SUBROUTINE 'PUFF'
C                     ESTABLISH TIME AT WHICH EACH PEAK OCCURRS
C                     (TPEAK(I)) AND THE REGION OF CONTRIBUTION
C                     (DTPEAK)
C
                     PEAK=XCORD(I)/USPEED
                     DO 100 II=1,100
                     IF(PUFFQ(ISOURCE,II).LE.0.) GO TO 101
                     TPEAK(II)=PUFFT(ISOURCE,II)+PEAK
  100                CONTINUE
  101                CONTINUE
                     DTPEAK=3.035*SIGY/USPEED
C
C                    LOOP THROUGH TIME TO FIND MAX CONCENTRATION
C
                     CMAX=0.
C
C                    LOOP THROUGH TIME PEAK OF PUFF II
C
                     DO 160 IPUF=1,100
                     IF(PUFFQ(ISOURCE,IPUF).LE.0.) GO TO 161
                     TIME=TPEAK(IPUF)-DTPEAK
                     IF(TIME.LT.0.) TIME=0.
                     DT=DTPEAK/5.
                     DO 150 IT=1,11
                     CONC(I)=0.
C                    LOOP THROUGH EACH PUFF WHICH COULD HAVE
C                    A CONTRIBUTION AT THIS TIME
                     DO 110 II=1,100
                     IF(PUFFQ(ISOURCE,II).LE.0.) GO TO 111
                     IF(ABS(TPEAK(II)-TPEAK(IPUF))
      Z              .GT.(2.*DTPEAK)) GO TO 110
                     T=TIME-PUFFT(ISOURCE,II)
                     IF(T.LT.0.) GO TO 110
                     CPUFF=2.*PUFFQ(ISOURCE,II)/(2.*PI)**1.5/SIGY/SIGY/SIG
                     CPUFF=CPUFF*EXP(-0.5*YCORD(I)*YCORD(I)/SIGY/SIGY)
                     CPUFF=CPUFF*EXP(-0.5*((XCORD(I)-USPEED*T)/SIGY)**2)
                     CONC(I)=CONC(I)+CPUFF
   110               CONTINUE
   111               CONTINUE
                     IF(CONC(I).GT.CMAX) CMAX=CONC(I)
                     TIME=TIME+DT
   150               CONTINUE
   160               CONTINUE
   161               CONTINUE
C
C                    CALL TRAP FOR DETERMINATION OF HEIGHT TERM
C                      (NO TRAPPING TERMS ARE ALLOWED)
C
                     CONC(I)=CMAX*TRAP(I)
                     GO TO 10
                     ENDIF
   22  CONTINUE
       IF(XCORD(I).GT.XEOUT) GO TO 30
C
C       ZONE 2
C
C
C       CALL SIG FOR SIGMA'S
C
       CALL SIG(XCORD(I),YCORD(I))
       SIGYF=SIGY+H(I)/8.
       XL=XLS(ISOURCE)+XCORD(I)
       XLFUNC=BOUNDL(XL)
       XINTEG=(XLFUNC-H(I))/SIGZ
       IF(IOPTION(1).EQ.1) THEN
C       PLUME MODEL
              CONC(I)=QRATE(ISOURCE)/SQRT(2.*PI)/SIGYF/USPEED/XLFUNC
              CONC(I)=CONC(I)*INTEGRAL(XINTEG)
              CONC(I)=CONC(I)*EXP(-0.5*YCORD(I)*YCORD(I)/SIGYF/SIGYF)
           ELSE
C       PUFF MODEL
             K=1./(2.*PI*SIGYF*SIGYF*XLFUNC)
             K=K*EXP(-0.5*YCORD(I)*YCORD(I)/SIGYF/SIGYF)
             K=K*INTEGRAL(XINTEG)
C          PUFF MODEL
C       THIS SECTION TAKEN FROM SUBROUTINE 'PUFF'
C                    ESTABLISH TIME AT WHICH EACH PEAK OCCURRS
C                    (TPEAK(I)) AND THE REGION OF CONTRIBUTION
C                    (DTPEAK)
C
                     PEAK=XCORD(I)/USPEED
                     DO 1100 II=1,100
                     IF(PUFFQ(ISOURCE,II).LE.0.) GO TO 1101
                     TPEAK(II)=PUFFT(ISOURCE,II)+PEAK
 1100                CONTINUE
 1101                CONTINUE
                     DTPEAK=3.035*SIGYF/USPEED
```

```
C
C                         LOOP THROUGH TIME TO FIND MAX CONCENTRATION
C
                          CMAX=0.
C
C                         LOOP THROUGH TIME PEAK OF PUFF II
C
                          DO 1160 IPUF=1,100
                          IF(PUFFQ(ISOURCE,IPUF).LE.0.) GO TO 1161
                          TIME=TPEAK(IPUF)-DTPEAK
                          IF(TIME.LT.0.) TIME=0.
                          DT=DTPEAK/5.
                          DO 1150 IT=1,11
                          CONC(I)=0.
C                         LOOP THROUGH EACH PUFF WHICH COULD HAVE
C                         A CONTRIBUTION AT THIS TIME
                          DO 1110 II=1,100
                          IF(PUFFQ(ISOURCE,II).LE.0.) GO TO 1111
                          IF(ABS(TPEAK(II)-TPEAK(IPUF))
     Z                    .GT.(2.*DTPEAK)) GO TO 1110
                          T=TIME-PUFFT(ISOURCE,II)
                          IF(T.LT.0.) GO TO 1110
                          CPUFF=PUFFQ(ISOURCE,II)
                          CPUFF=CPUFF*EXP(-0.5*((XCORD(I)-USPEED*T)/SIGYF)**2)
                          CONC(I)=CONC(I)+CPUFF
  1110                    CONTINUE
  1111                    CONTINUE
                          IF(CONC(I).GT.CMAX) CMAX=CONC(I)
                          TIME=TIME+DT
  1150                    CONTINUE
  1160                    CONTINUE
  1161                    CONTINUE
C
C                         CALL TRAP FOR DETERMINATION OF HEIGHT TERM
C                           (NO TRAPPING TERMS ARE ALLOWED)
C
                          CONC(I)=CMAX*TRAP(I)*K
                          GO TO 10
                          ENDIF
   30  CONTINUE
C
C        ZONE 3
C
       XOPRIME=XOFUNC(I,XEOUT)
       XPRIME=XCORD(I)-XOPRIME
       CALL SIG(XPRIME,YCORD(I))
       SIGUXP=SIGY
       XL=XLS(ISOURCE)+XCORD(I)
       XLFUNC=BOUNDL(XL)
       CALL SIG(XE,YCORD(I))
       SIGYF=SIGY+H(I)/8.
       IF(IOPTION(1).EQ.1) THEN
            CONC(I)=QRATE(ISOURCE)/SQRT(2.*PI)/SIGUXP/XLFUNC/USPEED
            CONC(I)=CONC(I)*EXP(-0.5*YCORD(I)*YCORD(I)/SIGUXP/SIGUXP)
          ELSE
            K=1./(2.*PI*SIGUXP*XLFUNC*USPEED)
            K=K*EXP(-0.5*YCORD(I)*YCORD(I)/SIGUXP/SIGUXP)
```

```
C               PUFF MODEL
C           THIS SECTION TAKEN FROM SUBROUTINE 'PUFF'
C                               ESTABLISH TIME AT WHICH EACH PEAK OCCURRS
C                                (TPEAK(I)) AND THE REGION OF CONTRIBUTION
C                                (DTPEAK)
C
                              PEAK=XPRIME/USPEED
                              DO 2100 II=1,100
                              IF(PUFFQ(ISOURCE,II).LE.0.) GO TO 2101
                              TPEAK(II)=PUFFT(ISOURCE,II)+PEAK
 2100                         CONTINUE
 2101                         CONTINUE
                              DTPEAK=3.035*SIGUXP/USPEED
C
C                             LOOP THROUGH TIME TO FIND MAX CONCENTRATION
C
                              CMAX=0.
C
C                             LOOP THROUGH TIME PEAK OF PUFF II
C
                              DO 2160 IPUF=1,100
                              IF(PUFFQ(ISOURCE,IPUF).LE.0.) GO TO 2161
                              TIME=TPEAK(IPUF)-DTPEAK
                              IF(TIME.LT.0.) TIME=0.
                              DT=DTPEAK/5.
                              DO 2150 IT=1,11
                              CONC(I)=0.
C                             LOOP THROUGH EACH PUFF WHICH COULD HAVE
C                             A CONTRIBUTION AT THIS TIME
                              DO 2110 II=1,100
                              IF(PUFFQ(ISOURCE,II).LE.0.) GO TO 2111
                              IF(ABS(TPEAK(II)-TPEAK(IPUF))
     Z                        .GT.(2.*DTPEAK)) GO TO 2110
                              T=TIME-PUFFT(ISOURCE,II)
                              IF(T.LT.0.) GO TO 2110
                              CPUFF=PUFFQ(ISOURCE,II)
                              CPUFF=CPUFF*EXP(-0.5*((XPRIME-USPEED*T)/SIGUXP)**2)
                              CONC(I)=CONC(I)+CPUFF
 2110                         CONTINUE
 2111                         CONTINUE
                              IF(CONC(I).GT.CMAX) CMAX=CONC(I)
                              TIME=TIME+DT
 2150                         CONTINUE
 2160                         CONTINUE
 2161                         CONTINUE
C
C                             CALL TRAP FOR DETERMINATION OF HEIGHT TERM
C                               (NO TRAPPING TERMS ARE ALLOWED)
C
                              CONC(I)=CMAX*TRAP(I)*K
                              ENDIF
   10  CONTINUE
       RETURN
       END
```

```
                                                                    30-Jun-1983 11:1
                                                                    30-Jun-1983 11:1
0001            SUBROUTINE LINK(ICASE)
          C
          C      ROUTINE TO LINK THE MAINLINE ROUTINES WITH
          C      THE MODIFIED VERSION OF H2SRISK
          C      FOR THE RISK/CONSEQUENCE ANALYSIS
          C
0002            IMPLICIT REAL*8 (A-H, O-Z)
0003            DIMENSION DUM(10)
0004            INCLUDE 'PARA.CMN'
        * C      COMMON PARA IS THE MAIN PARAMETER BLOCK
        * C      -CGX,CGY ARE THE LOCATIONS OF THE CG OF
        * C       THE AREA BEING REPRESENTED
        * C      -POP IS THE POPULATION REPRESENTED AT THE CG (IN # OF PEOPLE)
        * C      -AREA IS THE AREA OF THE REPRESENTED ELEMENT OF TERRAIN(KM**2)
        * C      -ELEV IS ELEVATION OF AREA
        * C      -H IS THE EFFECTIVE RELEASE HEIGHT
        * C      -XCORD,YCORD ARE THE COMPONENTS FOR THE CONCENTRATION CALC
        * C
0005    *       COMMON /PARA/ CGX(1000),CGY(1000),AREA(1000),POP(1000)
        *      Z,ELEV(1000),NP,H(1000),CONC(1000),XCORD(1000),YCORD(1000)
0006            INCLUDE 'ATMOS.CMN'
        * C
        * C     ATMOS CONTAINS ALL PERTINENT DATA FOR CONCENTRATION
        * C     CALCULATIONS AND DETERMINATION OF SIGMA'S
        * C
0007    *       COMMON /ATMOS/ QRATE(100),USPEED,HEIGHT(100),SIGY,
        *      ZSIGZ,SIGTHETA,SIGPHI,XT,RT,HT,C,AO,XLS(100),
        *      ZELEVSOUR(100),XLID,WDIR,SX(100),SY(100),
        *      ZILAKE,IWCLASS2,NSOURCE
0008            INCLUDE 'DISPD.CMN'
        * C      FACTORS FOR DISPERSION COEFFICIENTS
        * C
        * C   AA1,AA2,BB1,BB2,CC3 ARE FUNCTION OF WEATHER CLASS
        * C   CC1,CC2,DD1,DD2,     ARE FUNCTIONS OF ROUGHNESS
        * C
0009    *       COMMON/DISPD/ AA1(6),AA2(6),BB1(6),BB2(6),CC1(6)
        *      1,CC2(6),CC3(6),DD1(6),DD2(6),Z0(6)
0010            INCLUDE 'OPTIONS.CMN'
        * C
        * C      OPTIONS CONTAIN ALL OPTIONS REQUIRED FOR EXECUTION
        * C
0011    *       COMMON /OPTIONS/ IOPTION(11),IRUNCODE
        * C      IOPTION IS DEFINED AS FOLLOWS :
        * C                   IOPTION(1)  : PLUME MODEL=1; PUFF .NE. 1; IN/OUTDOOR=3
        * C                   IOPTION(2)  : SIGMA Y,Z OPTIONS 1,2,OR 3
        * C                   IOPTION(3)  : WEATHER CLASS (1=A,2=B,...6=F)
        * C                   IOPTION(4)  : TERRAIN ROUGHNESS(1,2,...6)
        * C                   IOPTION(5)  : GRAVITY EFFECT OPTION (1=INCLUDE)
        * C                   IOPTION(6)  : BUILDING EFFECT OPTION (1=INCLUDE)
        * C                   IOPTION(7)  : TERRAIN MODIFICATION (1=INCLUDE)
        * C                   IOPTION(8)  : TRAPPING OPTION (1=INCLUDE)
        * C                   IOPTION(9)  : LAKE BREEZE EFFECT (1=INCLUDE)
        * C                   IOPTION(10) : DEBUGGING SWITCH 1= ADDITIONAL OUTPUT
        * C                                                 2= TERRAIN PLOT PRODUCE
        * C                   IOPTION(11) : RELEASE TYPE 1=PASSIVE
        * C                                              2=VERTICAL JET
        * C                                              3=FLARE
```

```
              INCLUDE 'RISKS.CMN'
     *        COMMON /RISKS/V(10),FMAX(10),SPECA(10),SPECC(10),ZO(10),T(10),
     *       ZS(10),XTT(10),FO(10),D(10),XS(10),BETA,PROBAB
              INCLUDE 'LINKUP.CMN'
     *        COMMON /LINKUP/ PERC(10),FIXJ(1000,10),PROB(10),
     *       ZCLT(10,10),TCLT(10,10),PK(10),PJGRID(10),PJ(10),
     *       ZGRIDFAT(1000,10),ZNU(10),PROBJ(1000),J1
     * C
     * C       CONCENTRATION LETHAL DOSE = CLT
     * C       EXPOSURE TIMES FOR CLT    = TCLT
     * C
              IF(IRUNCODE.EQ.2) RETURN
              IF(IOPTION(10).NE.0) THEN
                          WRITE(3,52) ICASE,(PERC(KK),KK=1,10)
         52               FORMAT('1'///1X,3('-'),' DEBUGGING DUMP OF '
            Z             ,'PK''S ---     FOR CASE ',I2,/,
            Z             //' NODE #',10X,' PERCENTILES OF AFFECTED',
            Z             '  ( VALUES OF K )',//,
            Z             17X,10G11.4/)
                          ENDIF
             DO 10 I=1,NP
       C
       C       INITIALIZE VARIABLES FOR THIS GRID POINT
       C
             IF(CONC(I).LE.0.0) GO TO 24
             V(1)=USPEED
             XS(1)=CONC(I)
             D(1)=XCORD(I)/1000.
             ZO(1)=ZO(IOPTION(4))
       C       FO SHOULD BE A FUNCTION OF Y/SIGY
             FO(1)=0.80
       C
       C       LOOP THROUGH THE K PERCENTILES
       C       TO CALCULATE THE VALUES OF PK
       C
             DO 11 K=1,10
             PK(K)=1.0
             IF(TCLT(K,1).LE.0.) GO TO 13
       C
       C       LOOP THROUGH EXPOSURE TIMES OF EACH K CURVE
       C
             DO 12 J=1,10
             IF(TCLT(K,J).LE.0.) GO TO 11
             XTT(1)=CLT(K,J)
             T(1)=TCLT(K,J)
       C
       C       CALL RISK FOR PROBABILITY CALCULATION
       C
             IF(D(1).LE.0.0) THEN
                     PROBAB=0.
                     GO TO 40
                     ENDIF
             CALL RISK
        40   CONTINUE
       C
       C       FIND MINIMUM VALUE FOR K'TH PERCENTILE
       C             FOR 'AFFECTED' PROBABILITY
```

```
C
      IF(PROBAB. LT. PK(K)) PK(K)=PROBAB
   12 CONTINUE
   11 CONTINUE
   13 CONTINUE
      K=K-1
   24 CONTINUE
      IF(IOPTION(10). EQ. 1) THEN
                     WRITE(3,50) I, (PK(KK), KK=1, 10)
   50                FORMAT(' I, PK(K) :  ', I4, 2X, 10G11. 4)
                     ENDIF
C
C       LOOP THROUGH THE PJ'S TO INTERPOLATE FOR FIXJ'S
C
      DO 20 J=1, J1
      IF(CONC(I). LE. 0. ) THEN
                FIXJ(I, J)=0.
                GO TO 10
                ENDIF
      IF(PJ(J). GE. PK(1)) THEN
                FIXJ(I, J)=(PJ(J)-1. )/(PK(1)-1. )*PERC(1)
                GO TO 20
                ENDIF
      IF(PJ(J). LE. PK(K)) THEN
                FIXJ(I, J)=PJ(J)*(PERC(K)-1. )/PK(K)+1.
                GO TO 20
                ENDIF
C
C       LOOP THROUGH THE K'S TO FIND INTERPOLATION BOUNDS
C
      DO 22 II=2, K-1
      IF(PJ(J). GE. PK(II)) GO TO 23
   22 CONTINUE
   23 CONTINUE
      FIXJ(I, J)=PERC(II-1)+(PJ(J)-PK(II-1))/
     Z(PK(II)-PK(II-1))*(PERC(II)-PERC(II-1))
   20 CONTINUE
   21 CONTINUE
   10 CONTINUE
      WRITE(3,71) ICASE, (PJ(J), J=1, J1)
   71 FORMAT('1', //, 10X, 'NUMBER OF FATALITIES VERSUS '
     Z, 'PROBABILITY FOR CASE ', I4, //,
     Z' NODE #', 2X, 10X, 'PROBABILITY LEVEL', //
     Z, 9X, 10G11. 4)
      WRITE(3,73)
   73 FORMAT(//)
      DO 72 I=1, NP
C
C       SUM FOR EACH J OVER ENTIRE GRID
C
      DO 30 J=1, J1
      DUM(J)=FIXJ(I, J)*POP(I)
      IF(I. EQ. 1) THEN
           GRIDFAT(ICASE, J)=DUM(J)
           GO TO 30
           ENDIF
      GRIDFAT(ICASE, J)=GRIDFAT(ICASE, J)+DUM(J)
```

```
0084       30  CONTINUE
0085           WRITE(3,70) I,(DUM(J),J=1,J1)
0086       70  FORMAT(1X,I4,4X,10G11.4)
         C
         C       NOW HAVE PJ(J) VS GRIDFAT(ICASE,J) FOR
         C       THE N CASES OF PROBABILITY REFERENCE POINTS
         C
0087       72  CONTINUE
0088           IF(IOPTION(10).EQ.1) THEN
0089                            WRITE(3,60) ICASE
0090       60                   FORMAT('1',///,' SUM OF FATALITIES OVER',
             Z                 ' MAP FOR CASE ',I2,//,
             Z                 3X,' PJ(J)',7X,'FATALITIES')
0091                            DO 61 J=1,J1
0092                            WRITE(3,62) PJ(J),GRIDFAT(ICASE,J)
0093       62                   FORMAT(1X,G11.4,5X,G11.4)
0094       61                   CONTINUE
0095                            ENDIF
0096           RETURN
0097           END


PROGRAM SECTIONS

    Name                                          Bytes   Attributes

  0 $CODE                                          1267   PIC CON REL LCL   SHR   EXE   RD
  1 $PDATA                                          364   PIC CON REL LCL   SHR NOEXE   RD
  2 $LOCAL                                          128   PIC CON REL LCL NOSHR NOEXE   RD
  3 PARA                                          72004   PIC OVR REL GBL   SHR NOEXE   RD
  4 ATMOS                                          4908   PIC OVR REL GBL   SHR NOEXE   RD
  5 DISPD                                           480   PIC OVR REL GBL   SHR NOEXE   RD
  6 OPTIONS                                          48   PIC OVR REL GBL   SHR NOEXE   RD
  7 RISKS                                           896   PIC OVR REL GBL   SHR NOEXE   RD
  8 LINKUP                                       170084   PIC OVR REL GBL   SHR NOEXE   RD

ENTRY POINTS

   Address   Type  Name

 0-00000000        LINK

VARIABLES

   Address   Type  Name                    Address   Type  Name                    Address   Ty

 4-00000688  R*8   A0                    7-00000370  R*8   BETA                  4-00000680  R
 2-00000054  I*4   I                   AP-00000004@  I*4   ICASE                 2-00000060  I
 6-0000002C  I*4   IRUNCODE              4-00001324  I*4   IWCLASS2              2-0000005C  I
 2-00000058  I*4   K                     2-00000050  I*4   KK                    3-00009C40  I
 7-00000378  R*8   PROBAB                4-00000670  R*8   RT                    4-00000660  R
 4-00000648  R*8   SIGY                  4-00000650  R*8   SIGZ                  4-00000320  R
 4-00000CD0  R*8   XLID                  4-00000668  R*8   XT
```

```
                                                                        25-May-1983 17:03:
                                                                        19-Apr-1983 11:06:

0001              SUBROUTINE OUTPUT
0002              IMPLICIT REAL*8 (A-H,O-Z)
0003              INCLUDE 'PARA.CMN'
      * C          COMMON PARA IS THE MAIN PARAMETER BLOCK
      * C          -CGX,CGY ARE THE LOCATIONS OF THE CG OF
      * C           THE AREA BEING REPRESENTED
      * C          -POP IS THE POPULATION REPRESENTED AT THE CG (IN # OF PEOPLE)
      * C          -AREA IS THE AREA OF THE REPRESENTED ELEMENT OF TERRAIN(KM**2)
      * C          -ELEV IS ELEVATION OF AREA
      * C          -H IS THE EFFECTIVE RELEASE HEIGHT
      * C          -XCORD,YCORD ARE THE COMPONENTS FOR THE CONCENTRATION CALC
      * C
0004  *           COMMON /PARA/ CGX(1000),CGY(1000),AREA(1000),POP(1000)
      *          Z,ELEV(1000),NP,H(1000),CONC(1000),XCORD(1000),YCORD(1000)
0005              WRITE(3,20)
0006         20   FORMAT('1',//' --- DEBUGGING DUMP OF TERRAIN DATA ---'/
                 Z'    I,CGX,CGY,AREA,POP :  '///)
0007              DO 10 I=1,NP
0008              WRITE(3,11) I,CGX(I),CGY(I),AREA(I),POP(I)
0009         11   FORMAT(I4,4X,4G15.8)
0010         10   CONTINUE
0011              RETURN
0012              END


PROGRAM SECTIONS

    Name                                          Bytes   Attributes

  0 $CODE                                           153   PIC CON REL LCL   SHR   EXE   RD
  1 $PDATA                                           87   PIC CON REL LCL   SHR NOEXE   RD
  2 $LOCAL                                            8   PIC CON REL LCL NOSHR NOEXE   RD
  3 PARA                                          72004   PIC OVR REL GBL   SHR NOEXE   RD

ENTRY POINTS

    Address   Type  Name

  0-00000000        OUTPUT

VARIABLES

    Address   Type  Name                  Address   Type  Name

  2-00000000  I*4   I                   3-00009C40  I*4   NP
```

```
       C
       C      PLUME CALCULATES THE CONCENTRATION AT A POINT X,Y
       C      FROM THE SOURCE BY ASSUMING A PLUME DISPERSION
       C
              SUBROUTINE PLUME(ISOURCE)
              IMPLICIT REAL*8 (A-H,O-Z)
              INCLUDE 'ATMOS.CMN'
     * C
     * C      ATMOS CONTAINS ALL PERTINENT DATA FOR CONCENTRATION
     * C      CALCULATIONS AND DETERMINATION OF SIGMA'S
     * C
     *        COMMON /ATMOS/ QRATE(100),USPEED,HEIGHT(100),SIGY,
     *       ZSIGZ,SIGTHETA,SIGPHI,XT,RT,HT,C,AO,XLS(100),
     *       ZELEVSOUR(100),XLID,WDIR,SX(100),SY(100),
     *       ZILAKE,IWCLASS2,NSOURCE
              INCLUDE 'PARA.CMN'
     * C       COMMON PARA IS THE MAIN PARAMETER BLOCK
     * C       -CGX,CGY ARE THE LOCATIONS OF THE CG OF
     * C        THE AREA BEING REPRESENTED
     * C       -POP IS THE POPULATION REPRESENTED AT THE CG (IN # OF PEOPLE)
     * C       -AREA IS THE AREA OF THE REPRESENTED ELEMENT OF TERRAIN(KM**2)
     * C       -ELEV IS ELEVATION OF AREA
     * C       -H IS THE EFFECTIVE RELEASE HEIGHT
     * C       -XCORD,YCORD ARE THE COMPONENTS FOR THE CONCENTRATION CALC
     * C
     *        COMMON /PARA/ CGX(1000),CGY(1000),AREA(1000),POP(1000)
     *       Z,ELEV(1000),NP,H(1000),CONC(1000),XCORD(1000),YCORD(1000)
              DATA PI/3.14159265/
              DO 10 I=1,NP
              IF(XCORD(I).LE.0.) THEN
                          CONC(I)=0.
                          GO TO 10
                          ENDIF
       C
       C       CALL SIG TO CALCULATE SIGMAY AND SIGMAZ
       C
              CALL SIG(XCORD(I),YCORD(I))
              CONC(I)=QRATE(ISOURCE)/PI/SIGY/SIGZ/USPEED
              CONC(I)=CONC(I)*EXP(-0.5*YCORD(I)*YCORD(I)/SIGY/SIGY)
       C
       C       CALL TRAP TO CALCULATE TRAPPING TERMS IF CONSIDERED
       C
              CONC(I)=CONC(I)*TRAP(I)
          10  CONTINUE
              RETURN
              END
```

```
                                                                  25-May-1983 17:05:
                                                                  28-Apr-1983 17:00:

                   SUBROUTINE PROBOUT
                   IMPLICIT REAL*8 (A-H,O-Z)
                   INCLUDE 'LINKUP.CMN'
        *          COMMON /LINKUP/ PERC(10),FIXJ(1000,10),PROB(10),
        *         ZCLT(10,10),TCLT(10,10),PK(10),PJGRID(10),PJ(10),
        *         ZGRIDFAT(1000,10),ZNU(10),PROBJ(1000),J1
        * C
        * C         CONCENTRATION LETHAL DOSE = CLT
        * C         EXPOSURE TIMES FOR CLT    = TCLT
        * C
                  WRITE(3,10)
               10 FORMAT('1',//,16X,'OVERALL CONSEQUENCE OF RELEASE',//
                 Z,15X,'FATALITIES',10X,'PROBABILITY'/)
                  DO 11 INU=1,10
                  IF(ZNU(INU).LE.0.) GO TO 12
                  WRITE(3,13) ZNU(INU),PROB(INU)
               13 FORMAT(5X,2(G20.5,2X)/)
               11 CONTINUE
               12 CONTINUE
                  RETURN
                  END


PROGRAM SECTIONS

    Name                                      Bytes   Attributes

  0 $CODE                                       107   PIC CON REL LCL   SHR   EXE   RD
  1 $PDATA                                       86   PIC CON REL LCL   SHR NOEXE   RD
  2 $LOCAL                                        4   PIC CON REL LCL NOSHR NOEXE   RD
  3 LINKUP                                   170084   PIC OVR REL GBL   SHR NOEXE   RD

ENTRY POINTS

    Address   Type  Name

  0-00000000        PROBOUT

VARIABLES

    Address   Type  Name                Address   Type  Name

  2-00000000  I*4   INU               3-00029860  I*4   J1

ARRAYS

    Address   Type  Name                 Bytes  Dimensions

  3-00013920  R*8   CLT                    800  (10, 10)
  3-00000050  R*8   FIXJ                 80000  (1000, 10)
  3-00014050  R*8   GRIDFAT              80000  (1000, 10)
  3-00000000  R*8   PERC                    80  (10)
```

```
                                                              25-May-1983 17:03:
                                                               5-May-1983 17:11:

         C
         C      PUFF CALCULATES THE CONCENTRATION AT A POINT X,Y
         C      FROM THE SOURCE BY ASSUMING A PUFF DISPERSION
         C      REQUIRES THE INPUT OF THE SOURCE TERMS PUFFT & PUFFQ
         C
0001            SUBROUTINE PUFF(ISOURCE)
0002            IMPLICIT REAL*8 (A-H,O-Z)
0003            DIMENSION TPEAK(100)
0004            INCLUDE 'ATMOS.CMN'
       * C
       * C      ATMOS CONTAINS ALL PERTINENT DATA FOR CONCENTRATION
       * C      CALCULATIONS AND DETERMINATION OF SIGMA'S
       * C
0005   *        COMMON /ATMOS/ GRATE(100),USPEED,HEIGHT(100),SIGY,
       *       ZSIGZ,SIGTHETA,SIGPHI,XT,RT,HT,C,AO,XLS(100),
       *       ZELEVSOUR(100),XLID,WDIR,SX(100),SY(100),
       *       ZILAKE,IWCLASS2,NSOURCE
0006            INCLUDE 'OPTIONS.CMN'
       * C
       * C       OPTIONS CONTAIN ALL OPTIONS REQUIRED FOR EXECUTION
       * C
0007   *        COMMON /OPTIONS/ IOPTION(11),IRUNCODE
       * C       IOPTION IS DEFINED AS FOLLOWS :
       * C                       IOPTION(1)  : PLUME MODEL=1; PUFF .NE.1; IN/OUTDOOR=3
       * C                       IOPTION(2)  : SIGMA Y,Z OPTIONS 1,2,OR 3
       * C                       IOPTION(3)  : WEATHER CLASS (1=A,2=B,...6=F)
       * C                       IOPTION(4)  : TERRAIN ROUGHNESS(1,2,...6)
       * C                       IOPTION(5)  : GRAVITY EFFECT OPTION (1=INCLUDE)
       * C                       IOPTION(6)  : BUILDING EFFECT OPTION (1=INCLUDE)
       * C                       IOPTION(7)  : TERRAIN MODIFICATION (1=INCLUDE)
       * C                       IOPTION(8)  : TRAPPING OPTION (1=INCLUDE)
       * C                       IOPTION(9)  : LAKE BREEZE EFFECT (1=INCLUDE)
       * C                       IOPTION(10) : DEBUGGING SWITCH 1= ADDITIONAL OUTPUT
       * C                                                      2= TERRAIN PLOT PRODUCED
       * C
       * C                       IOPTION(11) : RELEASE TYPE 1=PASSIVE
       * C                                                  2=VERTICAL JET
       * C                                                  3=FLARE
       * C                                                  4=HEAVIER THAN AIR
       * C
0008            INCLUDE 'PUFF.CMN'
       * C
       * C        PUFF CONTAINS THE PUFF MODEL SPECIFIC SOURCE ARRAYS
       * C
0009   *        COMMON /PUFF/ PUFFT(100,100),PUFFQ(100,100),TAUB,TAU
0010            INCLUDE 'PARA.CMN'
       * C        COMMON PARA IS THE MAIN PARAMETER BLOCK
       * C        -CGX,CGY ARE THE LOCATIONS OF THE CG OF
       * C         THE AREA BEING REPRESENTED
       * C        -POP IS THE POPULATION REPRESENTED AT THE CG (IN # OF PEOPLE)
       * C        -AREA IS THE AREA OF THE REPRESENTED ELEMENT OF TERRAIN(KM**2)
       * C        -ELEV IS ELEVATION OF AREA
       * C        -H IS THE EFFECTIVE RELEASE HEIGHT
       * C        -XCORD,YCORD ARE THE COMPONENTS FOR THE CONCENTRATION CALC
       * C
0011   *        COMMON /PARA/ CGX(1000),CGY(1000),AREA(1000),POP(1000)
       *       Z,ELEV(1000),NP,H(1000),CONC(1000),XCORD(1000),YCORD(1000)
0012            DATA PI/3.14159265/
          C
```

```
C      CALL SIG TO CALCULATE SIGMAY AND SIGMAZ
C
C      LOOP THROUGH EACH GRID POINT
      DO 20 J=1,NP
      IF(XCORD(J).LE.0.) THEN
                  CONC(J)=0.
                  GO TO 20
                  ENDIF
      CALL SIG(XCORD(J),YCORD(J))
C
C      ESTABLISH TIME AT WHICH EACH PEAK OCCURRS (TPEAK(I))
C      AND THE REGION OF CONTRIBUTION DTPEAK (DTPEAK)
C
      PEAK=XCORD(J)/USPEED
      DO 100 I=1,100
      IF(PUFFQ(ISOURCE,I).LE.0.) GO TO 101
      TPEAK(I)=PUFFT(ISOURCE,I)+PEAK
  100 CONTINUE
  101 CONTINUE
      DTPEAK=3.035*SIGY/USPEED
C
C      LOOP THROUGH TIME TO FIND MAX CONCENTRATION
C
      CMAX=0.
C
C      LOOP THROUGH TIME PEAK OF PUFF I
C
      DO 60 IPUF=1,100
      IF(PUFFQ(ISOURCE,IPUF).LE.0.) GO TO 61
      TIME=TPEAK(IPUF)-DTPEAK
      IF(TIME.LT.0.) TIME=0.
      DT=DTPEAK/5.
      DO 50 IT=1,11
      CONC(J)=0.
C      LOOP THROUGH EACH PUFF WHICH COULD HAVE
C       A CONTRIBUTION AT THIS TIME
      DO 10 I=1,100
      IF(PUFFQ(ISOURCE,I).LE.0.) GO TO 11
      IF(ABS(TPEAK(I)-TPEAK(IPUF)).GT.2.*DTPEAK) GO TO 10
      T=TIME-PUFFT(ISOURCE,I)
      IF(T.LT.0.) GO TO 10
      CPUFF=2.*PUFFQ(ISOURCE,I)/(2.*PI)**1.5/SIGY/SIGY/SIGZ
      CPUFF=CPUFF*EXP(-0.5*YCORD(J)*YCORD(J)/SIGY/SIGY)
      CPUFF=CPUFF*EXP(-0.5*(XCORD(J)-USPEED*T)**2./SIGY/SIGY)
      CONC(J)=CONC(J)+CPUFF
   10 CONTINUE
   11 CONTINUE
      IF(CONC(J).GT.CMAX) CMAX=CONC(J)
      TIME=TIME+DT
   50 CONTINUE
   60 CONTINUE
   61 CONTINUE
C
C      CALL TRAP FOR DETERMINATION OF TRAPPING TERMS IN REQUIRED
C
      CONC(J)=CMAX*TRAP(J)
   20 CONTINUE
```

```
         C
         C      CALCULATE INDOOR/OUTDOOR EFFECT IF REQUIRED
         C
0052            IF(IOPTION(1).EQ.3) CALL INDOOR
0053            RETURN
0054            END


PROGRAM SECTIONS

    Name                               Bytes   Attributes

  0 $CODE                                668   PIC CON REL LCL   SHR   EXE   RD
  2 $LOCAL                               912   PIC CON REL LCL NOSHR NOEXE   RD
  3 ATMOS                               4908   PIC OVR REL GBL   SHR NOEXE   RD
  4 OPTIONS                               48   PIC OVR REL GBL   SHR NOEXE   RD
  5 PUFF                              160016   PIC OVR REL GBL   SHR NOEXE   RD
  6 PARA                               72004   PIC OVR REL GBL   SHR NOEXE   RD

ENTRY POINTS

    Address   Type  Name

  0-00000000        PUFF

VARIABLES

    Address   Type  Name                Address   Type  Name                Address   Ty

  3-00000688  R*8   A0                3-00000680  R*8   C                 2-00000338  R
  2-00000348  R*8   DT                2-00000330  R*8   DTPEAK            3-00000678  R
  3-00001320  I*4   ILAKE             2-00000368  I*4   IPUF              4-0000002C  I
  2-0000036C  I*4   IT                3-00001324  I*4   IWCLASS2          2-00000360  I
  3-00001328  I*4   NSOURCE           2-00000328  R*8   PEAK              2-00000320  R
  3-00000660  R*8   SIGPHI            3-00000658  R*8   SIGTHETA          3-00000648  R
  2-00000350  R*8   T                 5-00027108  R*8   TAU               5-00027100  R
  3-00000320  R*8   USPEED            3-00000CD8  R*8   WDIR              3-00000CD0  R

ARRAYS

    Address   Type  Name                 Bytes  Dimensions

  6-00003E80  R*8   AREA                  8000  (1000)
  6-00000000  R*8   CGX                   8000  (1000)
  6-00001F40  R*8   CGY                   8000  (1000)
  6-0000BB84  R*8   CONC                  8000  (1000)
  6-00007D00  R*8   ELEV                  8000  (1000)
  3-000009B0  R*8   ELEVSOUR               800  (100)
  6-00009C44  R*8   H                     8000  (1000)
  3-00000328  R*8   HEIGHT                 800  (100)
  4-00000000  I*4   IOPTION                 44  (11)
  6-00005DC0  R*8   POP                   8000  (1000)
```

```
      SUBROUTINE READIN(NCONT)
C     ************************************************
C     INPUT ROUTINE
C
      DIMENSION ARRAY(7)
C
      CHARACTER*4 OPTION(16), FIN, EN, AA, BLANK, AB, AC
      REAL MASS, INDEX
      INTEGER ZON, WIND, CAT, PR, A
      INTEGER*2 C
      CHARACTER*8 AD(9), TITLE
C
      COMMON/BAT/SIGTH, SIGTV, SIG3H, SIG3V, CAY, TEMP
      COMMON/AAA/XS, XT, HT, XA, POPDIS(20, 20), TX, A, J, XGRID(80), SHINT, NINT
      COMMON/BBB/ZO, ZON, WIND, MASS, PI, UZC, RO, HO, VO, G, RHO, RHOA, VEL(4, 6),
     *UZM, UAV, USTAR, XK, XL
      COMMON/HEET/ALPH, CAIR, CGAS, TAIR, RHOGAS, TGROUND(6, 4), ALSTAR, ALPI
      COMMON/CCC/CAS(3, 12, 4, 6), P(12, 4, 6), MNO, CAT, ZM, TT, NST(50), TCEN(50)
      COMMON/FFF/TA, TR, NVEL(6), NPOINT, NSEC, HTP, ALIM, NG
      COMMON/GGG/NHAZ, NTYPE, NTIME(3), TOXIC(50, 3), TEXP(50, 3), HLEV(3),
     *TAW, EKONK, PR(3)
      COMMON/EXTRA/AMASS, ARE, NFN, NHEAT, TEK(80), ROA(80), HRATE(80), CMASS,
     *NRANGE, DELRHO(80), AIRM(80), VELRAT(80), RICH(80), NENT
      COMMON/RITE/NALL, TITLE(13)
      COMMON/SOURCE/FMASS, FRHO, FTEMP
C
      DATA FIN, EN, BLANK/'CONT', 'END ', '    '/
      DATA OPTION/'HAZA', 'SITE', 'HEIG', 'ROUG', 'GAS ', 'AIR ', 'WEAT',
     *'CUT ', 'STAG', 'F-NL', 'AREA', 'HEAT', 'RANG', 'ALL ', 'ENTR', 'VAN '/
C
C     READIN ROUTINE COMMENCES
      NOPTI=16
      PI=3. 1415926
      G=9. 81
      IF(NCONT. EQ. 1)GO TO 7
      CALL DEFOLT
C     READ AND WRITE TITLE
7     CONTINUE
      WRITE(3, 200)
      WRITE(3, 200)
200   FORMAT(1H , 18X, 12(7H*******))
      WRITE(3, 201)TITLE(1)
201   FORMAT(1H , 18X, 2H* , 36X, A8, 36X, 2H *)
      WRITE(3, 207)
207   FORMAT(1H , 18X, 2H* , 36X, 4H****, 40X, 2H *)
      WRITE(3, 202)(TITLE(J), J=2, 7)
      WRITE(3, 202)(TITLE(J), J=8, 13)
202   FORMAT(1H , 18X, 2H* , 16X, 6A8, 16X, 2H *)
206   CONTINUE
      READ(6, 203)AB, AC, (AD(J), J=1, 9)
203   FORMAT(2A4, 9A8)
      IF(AB. EQ. BLANK)GO TO 204
      WRITE(3, 205)AC, (AD(J), J=1, 9)
205   FORMAT(1H , 18X, 2H* , 4X, A4, 9A8, 2H *)
      GO TO 206
204   WRITE(3, 200)
      WRITE(3, 200)
```

```
4       CONTINUE
C
C       READ INPUT DATA
        READ(6, 1)AA, B, C, (ARRAY(J), J=1, 7)
1       FORMAT(2A4, A2, 7G10. 3)
        IF(AA. EQ. FIN. OR. AA. EQ. EN)GO TO 20
        DO 2 J=1, NOPTI
        IF(AA. EQ. OPTION(J))GO TO 3
2       CONTINUE
        WRITE(3, 999)AA, B, C
        GO TO 4
3       CONTINUE
        GO TO (100, 101, 102, 103, 104, 105, 106, 107, 108, 109, 110, 111, 112, 114,
       *115, 116), J
C
C
100     CONTINUE
C       READ IN HAZARD LEVELS
        NHAZ=ARRAY(1)
C       NO. OF HAZARD LEVELS CONSIDERED - E. G. DISTRESS AND FATALITY
        NTYPE=ARRAY(2)
C       IDENTIFIES KIND OF HAZARD - E. G. FLAMMABLE(2) OR TOXIC(1)
        GO TO (90, 91), NTYPE
91      CONTINUE
        READ(6, 40)(HLEV(J), J=1, NHAZ)
40      FORMAT(8E10. 3)
C       HAZARD LEVELS IN KG/M**3 FOR FLAMMABLES
        GO TO 93
90      DO 94 J=1, NHAZ
        READ(6, 41)NTIME(J)
41      FORMAT(I3)
        NF=NTIME(J)
        READ(6, 40)(TOXIC(K, J), K=1, NF)
        READ(6, 40)(TEXP(K, J), K=1, NF)
C       ARRAYS OF TOXIC HAZARD LEVELS(KG/M**3)AND CORRESPONDING
C       EXPOSURE TIMES (SECS)
94      CONTINUE
93      CONTINUE
        GO TO 4
C
101     CONTINUE
C        READ IN POPULATION DISTRIBUTION
        NPOINT=ARRAY(1)
C       NUMBER OF RADII
        NSEC=ARRAY(2)
C       NUMBER OF SECTORS
        NG=NSEC+1
        READ(6, 40)(POPDIS(K, NG), K=1, NPOINT)
        READ(6, 40)((POPDIS(K, L), L=1, NSEC), K=1, NPOINT)
        GO TO 4
C
102     CONTINUE
C       HEIGHT OF WIND(METRES)
        ZM=ARRAY(1)
        GO TO 4
C
103     CONTINUE
```

```
C       ROUGHNESS LENGTH(METRES) AND CATEGORY
        ZO=ARRAY(1)
        IF(ZO. LT. 4. E-2)ZON=1
        IF(ZO. GE. 4. E-2)ZON=2
        IF(ZO. GE. 1. E-1)ZON=3
        IF(ZO. GE. 4. E-1)ZON=4
        IF(ZO. GE. 1. )ZON=5
        IF(ZO. GE. 4. )ZON=6
        GO TO 4
C
  104   CONTINUE
C       MASS AND DENSITY OF GAS
        FMASS=ARRAY(1)
C       MASS OF GAS RELEASED(KG)
        FRHO=ARRAY(2)
C       DENSITY OF SOURCE CYLINDER(KG/M**3)
        FTEMP=ARRAY(3)
C       TEMPERATURE(K) OF SOURCE CYLINDER
        GO TO 4
C
  105   CONTINUE
C       MASS OF AIR IN SOURCE CYLINDER(KG) AND AMBIENT DENSITY(KG/M**3)
        AMASS=ARRAY(1)
        RHOA=ARRAY(2)
        GO TO 4
C
  106   CONTINUE
C       WEATHER DATA
C       READ IN TABLE OF VELOCITY SUBDIVISIONS FOR EACH CATEGORY
        DO 26 CAT=1, 6
        NVEL(CAT)=ARRAY(CAT)
C       NO. OF VELOCITY SUBDIVISIONS IN EACH WEATHER CATEGORY
   26   CONTINUE
        DO 27 CAT=1, 6
        NN=NVEL(CAT)
        IF(NN. EQ. 0) GOTO 27
        READ(6, 40)(VEL(I, CAT), I=1, NN)
C       VELOCITIES(M/S) IN EACH WEATHER CATEGORY
   27   CONTINUE
C
        ADD=0.
        DO 31 CAT=1, 6
        NV=NVEL(CAT)
        IF(NV. EQ. 0)GO TO 31
        DO 32 NN=1, NV
        READ(6, 40)(P(IND, NN, CAT), IND=1, NSEC)
C       PROBABILTIES OF WIND BLOWING INTO SECTOR, IND, WITH VELOCITY, NN, IN
C       WEATHER CATEGORY, CAT.
        DO 33 I=1, NSEC
        ADD=ADD+P(I, NN, CAT)
   33   CONTINUE
   32   CONTINUE
   31   CONTINUE
        DO 43 I=1, 6
        NN=NVEL(I)
        IF(NN. EQ. 0)GO TO 43
        DO 44 NV=1, NN
        DO 42 J=1, NSEC
        P(J, NV, I)=P(J, NV, I)/ADD
C       NORMALISE PROBABILITIES
 42     CONTINUE
 44     CONTINUE
 43     CONTINUE
        GO TO 4
C
 107    CONTINUE
C       READ IN CUT-OFF HEIGHT(METRES) FOR SLUMPING
        HTP=ARRAY(1)
        GO TO 4
C
 108    CONTINUE
C       READ IN DENSITY DIFFERENCE(KG/M**3) FOR TERMINATION OF STAGE 3
        ALIM=ARRAY(1)
        GO TO 4
C
 109    CONTINUE
C       INDEX WHICH DETERMINES WHETHER F-N LINES ARE NEEDED
        NFN=1
        GO TO 4
C
 110    CONTINUE
C       AREA OF BASE
        ARE=ARRAY(1)
        GO TO 4
C
 111    CONTINUE
        NHEAT=1
C       NHEAT IS UNITY IF CLOUD HEATING IS TO BE EXAMINED
        ALPH=ARRAY(1)
        CAIR=ARRAY(2)
C       SP. HT. CAP. OF AIR(J/KG/K)
        CGAS=ARRAY(3)
C       SP. HT. CAP. (J/KG/K) OF GAS
        TAIR=ARRAY(4)
C       AMBIENT TEMPERATURE IN K
        RHOGAS=ARRAY(5)
C       DENSITY OF GAS (KG/M**3) AT AMBIENT TEMPERATURE
        INDEX=ARRAY(7)
        DO 5 I=1, 6
        NN=NVEL(I)
        IF(NN. EQ. 0)GO TO 5
        IF(INDEX. EQ. 1. 0)READ(6, 40)(TGROUND(I, J), J=1, NN)
C       GROUND TEMPERATURE(K) IN THE JTH VELOCITY SUBDIVISION OF THE ITH
C       WEATHER CATEGORY.
        IF(INDEX. EQ. 1)GO TO 5
        DO 6 NCAT=1, NN
        TGROUND(I, NCAT)=TAIR
 6      CONTINUE
 5      CONTINUE
        GO TO 4
C
 112    CONTINUE
C       INDEX WHICH DETERMINES WHETHER AREA/RANGE CALCULATIONS ARE REQD.
        NRANGE=1
```

```
             GO TO 4
       C
       114   CONTINUE
       C     OUTPUT FOR ALL WEATHER CATEGORIES/VELOCITY SUBDIVISIONS REQUIRED
             NALL=1
             GO TO 4
       C
       115   CONTINUE
       C     ENTRAINMENT CRITERION INDEX
             NENT=ARRAY(1)+0.001
             TAIR=ARRAY(2)
       C     AMBIENT TEMPERATURE(K)
             ALSTAR=ARRAY(3)
       C     ALPHA STAR IN ENTRAINMENT FORMULA(EDGE ENTRAINMENT)
             ALPI=ARRAY(4)
       C     ALPHA PRIME IN ENTRAINMENT FORMULA(TOP ENTRAINMENT)
             GO TO 4
       C
       116   CONTINUE
       C     VAN ULDEN(S CONSTANT
             CAY=ARRAY(1)
             GO TO 4
       C
       20    CONTINUE
             WRITE(3,50)
       50    FORMAT(1H0,' ')
             WRITE(3,51)
       51    FORMAT(1H0,'CHECK INPUT DATA')
       C
             IF(NENT.EQ.1.AND.NHEAT.EQ.0)WRITE(3,52)
       52    FORMAT(1H0,'WARNING-HEAT CARD MUST BE USED IF THE',
            *' EFFECT OF AIR ENTRAINMENT IS TO BE CONSIDERED'/
            *' IF HEATING OF THE CLOUD BY THE GROUND IS NOT TO',
            *' BE CONSIDERED,SET ALPHA TO ZERO')
             WRITE(3,58)(K,K=1,12)
       58    FORMAT(1H0,40X,'POPULATION DISTRIBUTION'/40X,5(5H*****)/
            *56X,'SECTORS',/,56X,7H*******,/,
            *'  RADII(M)',I4,11I9)
             DO 34 L=1,NPOINT
       34    WRITE(3,59)POPDIS(L,NQ),(POPDIS(L,K),K=1,NSEC)
       59    FORMAT(F7.0,12F9.0)
             WRITE(3,50)
       C
             WRITE(3,60)
       60    FORMAT(1H0,35X,'PARAMETERS OF DENSE GAS CLOUD'/35X,15(2H**)/' ')
             WRITE(3,61)ZM,Z0
       61    FORMAT(1H0,'HEIGHT AT WHICH INITIAL WIND SPEED IS GIVEN IS',E10.3,
            *' METRES'/' ROUGHNESS LENGTH IS',E10.3,' METRES')
             WRITE(3,62)FMASS,FRHO,FTEMP
       62    FORMAT(1H0,'MASS OF GAS IS',E10.3,' KG'/' DENSITY OF CLOUD IS',
            *E10.3,' KG/M**3'/' TEMPERATURE OF CLOUD IS',E10.3,' K')
             WRITE(3,214) AMASS,RHOA
       214   FORMAT(1H0,'INITIAL MASS OF AIR IS',E10.3,' KG',
            */' DENSITY OF AIR IS',E10.3,' KG/M**3')
             IF(NHEAT.EQ.0)GO TO 21
             WRITE(3,64)ALPH,TAIR
       64    FORMAT(1H0,'ALPHA=',E10.3/' AMBIENT TEMPERATURE=',E10.3,' K')
```

```
              WRITE(3,65)CAIR,CGAS,RHOGAS
        65    FORMAT(1HO,'SPECIFIC HEAT CAPACITY OF AIR IS',E10.3,' J/KG/K',
             */' SPECIFIC HEAT CAPACITY OF GAS IS',E10.3,' J/KG/K'/
             *' DENSITY OF GAS AT AMBIENT TEMPERATURE IS',E10.3,' KG/M**3')
              WRITE(3,85)
        85    FORMAT(1HO,' NPASQ  VEL(M/S) GROUND TEMP(K)')
              DO 76 I=1,6
              NZ=NVEL(I)
              IF(NZ.EQ.0)GO TO 76
              WRITE(3,86)(I,VEL(II,I),TGROUND(I,II),II=1,NZ)
        86    FORMAT(I3,1X,2E12.4)
        76    CONTINUE
        C
        21    CONTINUE
              WRITE(3,50)
              WRITE(3,67)(J,J=1,12)
        67    FORMAT(1HO,'PROBABILITY THAT THE WIND WILL BLOW INTO ',
             <'VARIOUS SECTORS',/,56X,'SECTORS',/,56X,7H*******,/,
             *' NPASQ  VEL(M/S) ',4X,I1,11I8)
              DO 68 CAT=1,6
              NZ=NVEL(CAT)
              IF(NZ.EQ.0)GO TO 68
              DO 81 NN=1,NZ
              U=VEL(NN,CAT)
        81    WRITE(3,82) CAT,U,(P(I,NN,CAT),I=1,NSEC)
        82    FORMAT(I3,1X,E12.4,12F8.5)
        68    CONTINUE
              WRITE(3,50)
        C
              GO TO (70,69),NTYPE
        70    CONTINUE
              WRITE(3,66)
        66    FORMAT(1HO,47X,'TOXICOLOGY DATA'/48X,5(3H***))
              WRITE(3,73)NHAZ
        73    FORMAT(1HO,'TOXIC GAS WITH'I2,' HAZARD LEVELS')
              GO TO 71
        69    CONTINUE
              WRITE(3,72)
        72    FORMAT(1HO,40X,'FLAMMABILITY DATA'/40X,9(2H**))
              WRITE(3,75)NHAZ
        75    FORMAT(1HO,'FLAMMABLE GAS WITH',I4,' HAZARD LEVELS')
              WRITE(3,14)(HLEV(J),J=1,NHAZ)
        14    FORMAT(1HO,'HAZARD LEVELS IN KG/M**3 ARE',5E12.4)
              WRITE(3,50)
              GO TO 15
        71    DO 96 J=1,NHAZ
              WRITE(3,97)J
        97    FORMAT(1H ,'HAZARD LEVEL CURVE FOR CASE NO. ',I2,/,' HAZARD LEVEL',
             *'S IN KG/M**3')
              NG=NTIME(J)
              WRITE(3,98)(TOXIC(NF,J),NF=1,NG)
        98    FORMAT(8E12.4)
              WRITE(3,99)
        99    FORMAT(1H ,'CORRESPONDING EXPOSURE TIMES IN SECONDS')
              WRITE(3,98)(TEXP(NF,J),NF=1,NG)
        96    CONTINUE
        C
```

```
15    CONTINUE
      IF(NENT.NE.0.OR.NHEAT.NE.0)GO TO 261
      WRITE(3,78)
78    FORMAT(1H0,30X,'INPUT PARAMETERS AND OPTIONS FOR SIMPLE 4 STAGE MO
     *DEL'/31X,27(2H**))
      WRITE(3,83)HTP,CAY
83    FORMAT(1H0,'TERMINATION OF SLUMPING OCCURS AT',E10.3,' METRES IF T
     *HIS IS GREATER THAN VAN ULDEN''S LIMIT'/,1X,'VAN ULDEN''S CONS',
     *'TANT IS',E10.3)
      WRITE(3,84)ALIM
84    FORMAT(1H0,'TRANSITION TO PASSIVITY OCCURS WHEN CENTRE-LINE',
     *' DENSITY DIFFERENCE IS',E10.3,' KG/M**3')
261   CONTINUE
      IF(NENT.EQ.0)GO TO 262
      IF(NENT.EQ.1)WRITE(3,79)
79    FORMAT(1H0,34X,'INPUT PARAMETERS AND OPTIONS'/35X,14(2H**))
      IF(NENT.EQ.1)WRITE(3,263)TAIR,ALSTAR,ALPI
263   FORMAT(1H0,'COX AND ROE ENTRAINMENT MODEL USED'/,1X,'AMBIENT TEM',
     *'PERATURE IS',E10.3,' K,ALPHA STAR IS',E10.3,',ALPHA PRIME IS',
     *E10.3)
262   CONTINUE
C
      IF(NFN.EQ.1) WRITE(3,181)
181   FORMAT(1H0,'F-N LINES CALCULATED')
      IF(ARE.GT.0) WRITE(3,182) ARE
182   FORMAT(1H0,'AREA OF BASE',E12.4,' M**2')
      IF(NHEAT.NE.0.AND.NENT.EQ.1.AND.ALPH.EQ.0.)WRITE(3,38)
38    FORMAT(1H0,'CLOUD HEATING FROM ENTRAINED AIR CONSIDERED')
      IF(NHEAT.NE.0.AND.NENT.EQ.1.AND.ALPH.NE.0.)WRITE(3,35)
35    FORMAT(1H0,'CLOUD HEATING FROM THE GROUND AND FROM ENTRAINED AIR',
     *' CONSIDERED')
      IF(NHEAT.NE.0.AND.NENT.EQ.0)WRITE(3,36)
36    FORMAT(1H0,'CLOUD HEATING FROM THE GROUND CONSIDERED')
      IF(NRANGE.EQ.1)WRITE(3,39)
39    FORMAT(1H0,'AREA-RANGE CALCULATIONS REQUIRED')
999   FORMAT(1H0,'WARNING-OPTION CARD ',2A4,A2,' NOT RECOGNISED',
     *'-IT HAS BEEN IGNORED')
      RETURN
      END
%FORT-W-ERROR 124, Mixed numeric and character elements in COMMON
        [RITE] in module READIN
```

```
    C
    C      ROUTINE RISK
    C      ADAPTED FROM PROGRAM H2SRISK
    C      PROGRAM TO CALCULATE PROBABILITIES OF
    C      CONCENTRATION PEAKS FROM :
    C               - EXPONENTIAL
    C               - WEIBULL
    C
          SUBROUTINE RISK
          IMPLICIT REAL*8(A-H,O-Z)
          REAL*8 N,NMAX,INT,NU,K,KK
          INTEGER CASE,SCASE
          EQUIVALENCE (XTT,XT)
          INCLUDE 'RISKS.CMN'
*         COMMON /RISKS/V(10),FMAX(10),SPECA(10),SPECC(10),ZO(10),T(10),
*        ZS(10),XTT(10),FO(10),D(10),XS(10),BETA,PROBAB
          DIMENSION SN1(1000),SN2(1000),NU(10),VAR(10),
         ZW1(10,10,3),PROB1(10,10,3),PROB2(10,10),
         ZPROB3(10,10),XT(10),
         ZK(10),C(10,10),IFLAG(10),COV(10)
          BYTE RESP,IWEIB,YCASE
          PI=3.141592654
          SCASE=0
    C      READ(1,119,ERR=103) V
    C      READ(1,119,ERR=103) FMAX
    C      READ(1,119,ERR=103) SPECC
    C      READ(1,119,ERR=103) SPECA
    C      READ(1,119,ERR=103) ZO
    C      READ(1,119,ERR=103) T
    C      READ(1,119,ERR=103) S
    C      READ(1,119,ERR=103) BETA
    C      READ(1,119,ERR=103) XT
    C      READ(1,119,ERR=103) FO
    C      READ(1,119,ERR=103) D
    C      READ(1,119,ERR=103) XS
    C 119  FORMAT(10F10.5)
          M=25
          IWEIB='N'
    C
    C     DATA ON FILE
    C
          ITE=1
          IXTE=1
          IZOE=1
          ISE=1
          IVE=1
          ISPECE=1
          IDE=1
          IFOE=1
          IXSE=1
          DO 180 IT=1,ITE
          DO 181 IXT=1,IXTE
          DO 131 IZO=1,IZOE
          DO 132 IS=1,ISE
          DO 133 IV=1,IVE
          DO 134 ISPEC=1,ISPECE
    C      IF(SCASE.EQ.0) GO TO 913
```

```
C       IF(CASE. NE. SCASE) GO TO 921
C 913   CONTINUE
C
C*************************************************************
C        INSERT SPECIAL CASE CARDS HERE
C
C       IF((IV. EQ. 1). AND. (ISPEC. EQ. 2)) GO TO 134
C       IF((IV. EQ. 3). AND. ((ISPEC. EQ. 1). OR. (ISPEC. EQ. 3))) GO TO 134
C       IF((IXT. EQ. 2). AND. (IT. EQ. 2)) GO TO 134
C       IF((IXT. EQ. 1). AND. (IT. EQ. 1)) GO TO 134
C
C*************************************************************
C
        DO 120 ID=1, IDE
C        CALCULATE FRICTION VELOCITY
        U=0. 4*V(IV)/(DLOG(1000. /ZO(IZO)))
C        CALCULATE TRAVEL TIME TO RECEPTOR
        TT=D(ID)/V(IV)
C        TRANSFORM REFERENCE FRAME TO EULERIAN
        T1=TT/BETA
C        CALCULATE FREQUENCY AT SPECTRAL PEAK
        NMAX=FMAX(ISPEC)*V(IV)/10.
C
C        CALCULATE LIMITS OF INTEGRATION
C
        TEST1=1. /T(IT)
        TEST2=1. /TT
        IF(TEST1. LT. TEST2) GO TO 106
        UPPERN=TEST2
        GO TO 107
 106    UPPERN=TEST1
 107    CONTINUE
        IF(M. EQ. 0) M=25
        MM1=M-1
        FM=FLOAT(MM1)
        INT=UPPERN/FM
        N=0.
        SN1(1)=0.
        SN2(1)=0.
        DO 110 I=2, M
        N=N+INT
        S1=(N/NMAX)/((1. +1. 5*(N/NMAX)**SPECA(ISPEC))**(5. *SPECA(ISPEC)/
       Z3. ))
        S1=S1*(DSIN(PI*N*T(IT))/(PI*N*T(IT)))**2.
        S1=S1*(DSIN(PI*N*T1)/(PI*N*T1))**2.
        S1=S1*(1. -(DSIN(PI*N*S(IS))/(PI*N*S(IS)))**2. )
        SN1(I)=S1*N
        SN2(I)=S1/N
 110    CONTINUE
        CALL FSIMP(SN1, UPPERN, M, AN)
        CALL FSIMP(SN2, UPPERN, M, AD)
        NU(ID)=DSQRT(AN/AD)
        VAR(ID)=10. *AD*SPECC(ISPEC)*U**2.
        COV(ID)=DSQRT(VAR(ID))/V(IV)
        IFLAG(ID)=0
        IF(NU(ID)*S(IS). LT. 1. ) IFLAG(ID)=1
        IF(IFLAG(ID). EQ. 1) GO TO 120
```

```
      DO 122 IXS=1,IXSE
C
C      CALCULATE THE EXTREME VALUE DISTRIBUTION
C
C
      IF(IWEIB.EQ.'N') GO TO 409
      IF(IXS.EQ.1) K(ID)=0.
      IF(IXS.EQ.1) K(ID)=ROOT(COV(ID))
      KK=1.+1./K(ID)
      C(ID,IXS)=XS(IXS)/GAM(KK)
      PROB3(ID,IXS)=K(ID)/C(ID,IXS)*(DLOG(NU(ID)*S(IS)))
     Z**(1.-1./K(ID))
     Z*XT(IXT)-K(ID)*DLOG(NU(ID)*S(IS))
      PROB3(ID,IXS)=DEXP(-1.*DEXP(-1.*PROB3(ID,IXS)))
      PROB3(ID,IXS)=1.-PROB3(ID,IXS)
  409 CONTINUE
      DO 931 IFO=1,IFOE
      AAA=FO(IFO)/XS(IXS)
      W1(ID,IXS,IFO)=XS(IXS)/FO(IFO)
     Z*DLOG(NU(ID)*S(IS)*FO(IFO))
      PROB1(ID,IXS,IFO)=1.-DEXP(-1.*DEXP(-1.*AAA*(XT(IXT)-W1(ID,IXS,IFO)
     Z)))
  931 CONTINUE
  122 CONTINUE
  120 CONTINUE
C      WRITE(2,124) CASE,CASE,V(IV),FMAX(ISPEC),SPECC(ISPEC),SPECA(ISPEC)
C     Z,ZO(IZO),T(IT),S(IS),BETA,XT(IXT)
C124   FORMAT('1',//20X,
C     Z'H2S RISK STUDY - CASE ',I3,70X,'CASE= ',I3,/
C     Z19X,27('-'),/////
C     Z' FIXED INPUT PARAMETERS :'
C     Z2X,'V= ',F5.1,'M/S',3X,'FMAX= ',F5.3,'HZ',/
C     Z27X,'C= ',F5.3,9X,'A= ',F5.3,/
C     Z26X,'ZO= ',F5.1,'CM',7X,'T= ',F5.1,'S',/
C     Z27X,'S= ',F5.0,'S',3X,2X,'BETA= ',F5.2,/
C     Z33X,'XT= ',F5.0,'MG/M**3',//////
C     Z10X,'DOWNWIND',20X,' CYCLE',43X,'VARIANCE',9X,'COEFFICIENT OF ',
C     Z/,11X,'RANGE',91X,'VARIATION'/
C     Z,12X,'(M)',25X,'(HZ)'/)
C     WRITE(3,161) CASE
C161   FORMAT('0 CASE ',I3,' COMPLETED')
C      DO 126 I=1,IDE
C      WRITE(2,125) D(I),NU(I),VAR(I),COV(I)
C125   FORMAT(10X,F6.0,20X,E10.3,40X,E10.3,10X,E10.3)
C126   CONTINUE
C      WRITE(2,127)
C127   FORMAT(//////
C     Z,1X,'DOWNWIND ',6X,'XS',5X,3(3X,
C     Z'PROBABILITY '),37X,'K',16X,'C')
C      WRITE(2,201)
C201   FORMAT('+',86X,'PROBABILITY ')
C      WRITE(2,472) (FO(I),I=1,3)
C472   FORMAT(2X,'RANGE',18X,3('(EXPONENTIAL)',2X),18X,'(WEIBULL)',
C     Z/26X,3('(FO = ',F4.2,')',4X))
C      DO 130 J=1,IXSE
C      DO 128 I=1,IDE
C      IF(IFLAG(I).EQ.1) GO TO 855
```

```
C       WRITE(2,129) D(I),XS(J),PROB1(I,J,1),PROB1(I,J,2),PROB1(I,J,3),
C      ZK(I),C(I,J)
C129    FORMAT(1X,F6.0,7X,F5.0,2X,3(5X,E10.3),36X,F7.4,10X,F8.4)
C       IF(IWEIB.EQ.'Y') WRITE(2,471) PROB3(I,J)
C471    FORMAT('+',86X,E10.3)
C       IF(IWEIB.NE.'Y') WRITE(2,481)
C       GO TO 856
C855    CONTINUE
C       WRITE(2,857) D(I),XS(J)
C857    FORMAT(1X,F6.0,7X,F5.0,2X,3(6X,'***---***'),27X,F10.4,10X,F10.4)
C       IF(IWEIB.EQ.'Y') WRITE(2,843)
C843    FORMAT('+',87X,'***---***')
C       IF(IWEIB.NE.'Y') WRITE(2,481)
C481    FORMAT('+',90X,'--')
C856    CONTINUE
C128    CONTINUE
C       WRITE(2,159)
C159    FORMAT(' ')
C130    CONTINUE
C921    CONTINUE
      CASE=CASE+1
 134  CONTINUE
 133  CONTINUE
 132  CONTINUE
 131  CONTINUE
 181  CONTINUE
 180  CONTINUE
      PROBAB=PROB1(1,1,1)
      RETURN
      END
```

25-May-1983 17: 06:
24-May-1983 09: 48:

```
      SUBROUTINE ROOT1(S)
      DIMENSION S(10), A(10)
      EQUIVALENCE (A(1), FLAG),    (A(2), X3),     (A(3), Y3),
     X   (A(4), X1),       (A(5), Y1),      (A(6), X2),      (A(7), Y2),
     X   (A(8), NIT),      (A(9), J),       (A(10), NTOGO)
      DO 109 I=1, 10
  109 A(I)=S(I)
      IF(FLAG) 20, 101, 100
  101 NIT=Y3
      J=4
      IF(NIT. LE. 0) J=5
   16 NTOGO=50
    4 FLAG=2. 0
   99 DO 110 I=1, 10
  110 S(I)=A(I)
      RETURN
  100 IF(Y3. EQ. 0. 0) GO TO 104
      IF(J. LE. 6. AND. J. GT. 3) GO TO 11
      IF((Y3. GT. 0. 0. AND. Y2. GT. 0. 0). OR. (Y3. LT. 0. 0. AND. Y2. LT. 0. 0))GO TO 12
      J=0
   23 X1=X2
      Y1=Y2
      IF(J. NE. 0) GO TO 103
   11 X2=X3
      Y2=Y3
      IF(J. LE. 1) GO TO 17
      IF(J. EQ. 2. OR. J. GT. 5) GO TO 14
      IF(J. NE. 5) GO TO 18
      J=2
   22 IF(X1. EQ. X3. AND. J. LE. 2) GO TO 100
      X3=X1
  103 NTOGO=NTOGO-1
      IF(NTOGO. GT. 0) GO TO 4
   98 FLAG=-2. 0
      GO TO 99
   25 J=1
      GO TO 11
   12 IF(J. GT. 6) GO TO 25
      IF(J-2) 105, 19, 11
  105 IF(J. EQ. 1) Y1=Y1+Y3
      Y1=Y1/2. 0
      GO TO 11
   19 IF(ABS(Y3). GE. ABS(Y2)) GO TO 14
      GO TO 11
    9 X3=X1+X3
      GO TO 16
   13 J=7
   15 X3=(X2+X3)/2. 0
      GO TO 103
   20 IF(J. NE. 0) GO TO (13, 14, 21, 21, 106, 98, 15), J
      GO TO 15
  106 J=6
      GO TO 22
   18 J=3
   21 NIT=NIT-1
      IF(NIT. GT. 0) GO TO 9
      IF(J. GT. 3) GO TO 98
```

```
        14    X3=1.001*X2
              GO TO 170
        17    X3=Y2-Y1
        170   IF(X3.EQ.0.0) X3=1.0E-6
              IF(J.LE.1) GO TO 107
              J=7
              GO TO 23
        107   Y3=Y2/X3
              DO 108 I=1,2
        108   Y3=SIGN( MAX (ABS(1.0-Y3),.01),(1.0-Y3))
              X3=X2+Y3*(X1-X2)
              IF(J.NE.0) GO TO 103
              IF(ABS(X1-X2)/(ABS(X1)+ABS(X2)).GT.0.5E-5)GO TO 103
        104   FLAG=0.0
              GO TO 99
              END


PROGRAM SECTIONS

    Name                                          Bytes   Attributes

  0 $CODE                                           569   PIC CON REL LCL   SHR   EXE    RD
  2 $LOCAL                                           88   PIC CON REL LCL NOSHR NOEXE   RD

ENTRY POINTS

    Address   Type  Name

  0-00000000        ROOT1

VARIABLES

    Address   Type  Name                   Address   Type  Name                    Address   Typ

  2-00000000  R*4   FLAG                2-00000028   I*4   I                    2-00000020   I*
  2-00000024  I*4   NTOGO               2-0000000C   R*4   X1                   2-00000014   R*
  2-00000010  R*4   Y1                  2-00000018   R*4   Y2                   2-00000008   R*

ARRAYS

    Address   Type  Name                             Bytes  Dimensions

  2-00000000  R*4   A                                   40  (10)
 AP-00000004@ R*4   S                                   40  (10)
```

```
       C
       C       SUBROUTINE SIG CALCULATES THE VALUE OF
       C       THE DISPERSION COEFFICIENTS SIGMA Y,Z
       C       - THREE OPTIONS ARE AVAILABLE TO SIGMA
       C         AND TWO ADJUSTMENTS ARE POSSIBLE
       C
              SUBROUTINE SIG(X,Y)
              IMPLICIT REAL*8 (A-H,O-Z)
              INCLUDE 'OPTIONS.CMN'
     * C
     * C       OPTIONS CONTAIN ALL OPTIONS REQUIRED FOR EXECUTION
     * C
     *        COMMON /OPTIONS/ IOPTION(11),IRUNCODE
     * C       IOPTION IS DEFINED AS FOLLOWS :
     * C                 IOPTION(1)  : PLUME MODEL=1; PUFF .NE. 1; IN/OUTDOOR=3
     * C                 IOPTION(2)  : SIGMA Y,Z OPTIONS 1,2,OR 3
     * C                 IOPTION(3)  : WEATHER CLASS (1=A,2=B,...6=F)
     * C                 IOPTION(4)  : TERRAIN ROUGHNESS(1,2,...6)
     * C                 IOPTION(5)  : GRAVITY EFFECT OPTION (1=INCLUDE)
     * C                 IOPTION(6)  : BUILDING EFFECT OPTION (1=INCLUDE)
     * C                 IOPTION(7)  : TERRAIN MODIFICATION (1=INCLUDE)
     * C                 IOPTION(8)  : TRAPPING OPTION (1=INCLUDE)
     * C                 IOPTION(9)  : LAKE BREEZE EFFECT (1=INCLUDE)
     * C                 IOPTION(10) : DEBUGGING SWITCH 1= ADDITIONAL OUTPUT
     * C                                                2= TERRAIN PLOT PRODUCED
     * C                 IOPTION(11) : RELEASE TYPE 1=PASSIVE
     * C                                            2=VERTICAL JET
     * C                                            3=FLARE
     * C                                            4=HEAVIER THAN AIR
              INCLUDE 'ATMOS.CMN'
     * C
     * C      ATMOS CONTAINS ALL PERTINENT DATA FOR CONCENTRATION
     * C      CALCULATIONS AND DETERMINATION OF SIGMA'S
     * C
     *        COMMON /ATMOS/ QRATE(100),USPEED,HEIGHT(100),SIGY,
     *       ZSIGZ,SIGTHETA,SIGPHI,XT,RT,HT,C,AO,XLS(100),
     *       ZELEVSOUR(100),XLID,WDIR,SX(100),SY(100),
     *       ZILAKE,IWCLASS2,NSOURCE
       C
       C       DETERMINE WHICH OF THE THREE OPTIONS THAT ARE
       C       TO BE USED FOR CALCULATING THE SIGMA'S
       C
              IF(IOPTION(2).EQ.1) CALL SIG1(X,Y)
              IF(IOPTION(2).EQ.2) THEN
                        IF(ILAKE.EQ.1) THEN
                              CALL SIG2(X,Y,IWCLASS2)
                            ELSE
                              CALL SIG2(X,Y,IOPTION(3))
                              ENDIF
                        ENDIF
              IF(IOPTION(2).EQ.3) THEN
                        IF(ILAKE.EQ.1) THEN
                              CALL SIG3(X,Y,IWCLASS2,IOPTION(4))
                            ELSE
                              CALL SIG3(X,Y,IOPTION(3),IOPTION(4))
                              ENDIF
                        ENDIF
```

```
        C
        C      CALL SIGADJ TO TEST FOR ANY ADJUSTMENTS TO THE SIGMA'S
        C
0022          CALL SIGADJ(X,Y)
0023          RETURN
0024          END



PROGRAM SECTIONS

   Name                                      Bytes   Attributes

 0 $CODE                                       165   PIC CON REL LCL   SHR   EXE   RD
 2 $LOCAL                                       84   PIC CON REL LCL NOSHR NOEXE   RD
 3 OPTIONS                                      48   PIC OVR REL GBL   SHR NOEXE   RD
 4 ATMOS                                      4908   PIC OVR REL GBL   SHR NOEXE   RD

ENTRY POINTS

   Address   Type  Name

 0-00000000        SIG

VARIABLES

   Address   Type  Name                Address   Type  Name                Address   Ty

 4-00000688  R*8   AO               4-00000680  R*8   C                 4-00000678  R
 3-0000002C  I*4   IRUNCODE         4-00001324  I*4   IWCLASS2          4-00001328  I
 4-00000660  R*8   SIGPHI           4-00000658  R*8   SIGTHETA          4-00000648  R
 4-00000320  R*8   USPEED           4-00000CD8  R*8   WDIR             AP-00000004@ R
 4-00000668  R*8   XT              AP-00000008@ R*8   Y

ARRAYS

   Address   Type  Name                  Bytes  Dimensions

 4-000009B0  R*8   ELEVSOUR                800  (100)
 4-00000328  R*8   HEIGHT                  800  (100)
 3-00000000  I*4   IOPTION                  44  (11)
 4-00000000  R*8   QRATE                   800  (100)
 4-00000CE0  R*8   SX                      800  (100)
 4-00001000  R*8   SY                      800  (100)
 4-00000690  R*8   XLS                     800  (100)
```

```
      C
      C     OPTION 1 FOR SIGMA'S
      C
            SUBROUTINE SIG1(X,Y)
            IMPLICIT REAL*8 (A-H,O-Z)
            DIMENSION XI(7),FOFX(7)
            INCLUDE 'ATMOS.CMN'
    * C
    * C     ATMOS CONTAINS ALL PERTINENT DATA FOR CONCENTRATION
    * C     CALCULATIONS AND DETERMINATION OF SIGMA'S
    * C
    *       COMMON /ATMOS/ GRATE(100),USPEED,HEIGHT(100),SIGY,
    *      ZSIGZ,SIGTHETA,SIGPHI,XT,RT,HT,C,AO,XLS(100),
    *      ZELEVSOUR(100),XLID,WDIR,SX(100),SY(100),
    *      ZILAKE,IWCLASS2,NSOURCE
            DATA XI/100.,200.,400.,1000.,2000.,5000.,10000./
            DATA FOFX/0.8,0.7,0.65,0.6,0.5,0.4,0.33/
      C
      C     CALCULATE F OF X  BY INTERPOLATION OF VALUES
      C
            IF(X.LE.100.) THEN
                 FX=0.8
                 GO TO 10
                 ENDIF
            IF(X.GE.10000.) THEN
                 FX=0.33*(10000./X)**0.5
                 GO TO 10
                 ENDIF
      C
      C     FIND BOUNDING VALUES OF XI FOR INTERPOLATION
      C
            DO 20 I=2,6
            IF(X.LE.XI(I)) GO TO 21
         20 CONTINUE
         21 CONTINUE
            X1=XI(I-1)
            X2=XI(I)
            F1=FOFX(I-1)
            F2=FOFX(I)
            FX=(F2-F1)/(X2-X1)*(X-X1)+F1
         10 CONTINUE
            SIGY=SIGTHETA*X*FX
            SIGZ=SIGPHI*X
            RETURN
            END
```

```
          C
          C      OPTION 2 - BRIGGS MODEL
          C
                 SUBROUTINE SIG2(X,Y,ICL)
                 IMPLICIT REAL*8 (A-H,O-Z)
                 INCLUDE 'ATMOS.CMN'
        * C
        * C      ATMOS CONTAINS ALL PERTINENT DATA FOR CONCENTRATION
        * C      CALCULATIONS AND DETERMINATION OF SIGMA'S
        * C
        *        COMMON /ATMOS/ GRATE(100),USPEED,HEIGHT(100),SIGY,
        *       ZSIGZ,SIGTHETA,SIGPHI,XT,RT,HT,C,AO,XLS(100),
        *       ZELEVSOUR(100),XLID,WDIR,SX(100),SY(100),
        *       ZILAKE,IWCLASS2,NSOURCE
                 SIGY=X*(1.+0.0001*X)**-0.5
                 GOTO(10,20,30,40,50,60) ICL
             10  CONTINUE
                 SIGY=0.22*SIGY
                 SIGZ=0.20*X
                 GO TO 70
             20  CONTINUE
                 SIGY=0.16*SIGY
                 SIGZ=0.12*X
                 GO TO 70
             30  CONTINUE
                 SIGY=0.11*SIGY
                 SIGZ=0.08*X*(1.+0.0002*X)**-0.5
                 GO TO 70
             40  CONTINUE
                 SIGY=0.08*SIGY
                 SIGZ=0.06*X*(1.+0.0015*X)**-0.5
                 GO TO 70
             50  CONTINUE
                 SIGY=0.06*SIGY
                 SIGZ=0.03*X*(1.+0.0003*X)**-1.
                 GO TO 70
             60  CONTINUE
                 SIGY=0.04*SIGY
                 SIGZ=0.016*X*(1.+0.0003*X)**-1.
             70  CONTINUE
                 RETURN
                 END
        C
        C       OPTION 3 - HOSKER MODEL
        C
                 SUBROUTINE SIG3(X,Y,ICL,IRG)
                 IMPLICIT REAL*8 (A-H,O-Z)
                 INCLUDE 'DISPD.CMN'
      * C         FACTORS FOR DISPERSION COEFFICIENTS
      * C
      * C    AA1,AA2,BB1,BB2,CC3 ARE FUNCTION OF WEATHER CLASS
      * C    CC1,CC2,DD1,DD2,     ARE FUNCTIONS OF ROUGHNESS
      * C
      *          COMMON/DISPD/ AA1(6),AA2(6),BB1(6),BB2(6),CC1(6)
      *         1,CC2(6),CC3(6),DD1(6),DD2(6),ZO(6)
                 INCLUDE 'ATMOS.CMN'
      * C
      * C        ATMOS CONTAINS ALL PERTINENT DATA FOR CONCENTRATION
      * C        CALCULATIONS AND DETERMINATION OF SIGMA'S
      * C
      *          COMMON /ATMOS/ GRATE(100),USPEED,HEIGHT(100),SIGY,
      *         ZSIGZ,SIGTHETA,SIGPHI,XT,RT,HT,C,AO,XLS(100),
      *         ZELEVSOUR(100),XLID,WDIR,SX(100),SY(100),
      *         ZILAKE,IWCLASS2,NSOURCE
                 SIGY=CC3(ICL)*X/(SQRT(1.0+0.0001*X))
                 G=AA1(ICL)*X**BB1(ICL)/(1.0+AA2(ICL)*X**BB2(ICL))
                 ZZ=ZO(IRG)
                 IF(ZZ.GT.0.10) GO TO 11
                 F=LOG(CC1(IRG)*X**DD1(IRG)/(1.0+CC2(IRG)*X**DD2(IRG)))
                 GO TO 12
              11 F=LOG(CC1(IRG)*X**DD1(IRG)*(1.0+1.0/(CC2(IRG)*X**DD2(IRG))))
              12 SIGZ=G*F
                 RETURN
                 END
```

```
    C
    C       SIGADJ COMPUTES ANY ADJUSTMENT TO
    C       THE DISPERSION COEFFICIENTS SIGMA Y,Z
    C
            SUBROUTINE SIGADJ(X,Y)
            IMPLICIT REAL*8 (A-H,O-Z)
            INCLUDE 'OPTIONS.CMN'
  * C
  * C       OPTIONS CONTAIN ALL OPTIONS REQUIRED FOR EXECUTION
  * C
  *         COMMON /OPTIONS/ IOPTION(11),IRUNCODE
  * C        IOPTION IS DEFINED AS FOLLOWS :
  * C                   IOPTION(1)  : PLUME MODEL=1; PUFF .NE.1; IN/OUTDOOR=3
  * C                   IOPTION(2)  : SIGMA Y,Z OPTIONS 1,2,OR 3
  * C                   IOPTION(3)  : WEATHER CLASS (1=A,2=B,...6=F)
  * C                   IOPTION(4)  : TERRAIN ROUGHNESS(1,2,...6)
  * C                   IOPTION(5)  : GRAVITY EFFECT OPTION (1=INCLUDE)
  * C                   IOPTION(6)  : BUILDING EFFECT OPTION (1=INCLUDE)
  * C                   IOPTION(7)  : TERRAIN MODIFICATION (1=INCLUDE)
  * C                   IOPTION(8)  : TRAPPING OPTION (1=INCLUDE)
  * C                   IOPTION(9)  : LAKE BREEZE EFFECT (1=INCLUDE)
  * C                   IOPTION(10) : DEBUGGING SWITCH 1= ADDITIONAL OUTPUT
  * C                                                  2= TERRAIN PLOT PRODUCED
  * C                   IOPTION(11) : RELEASE TYPE 1=PASSIVE
  * C                                              2=VERTICAL JET
  * C                                              3=FLARE
  * C                                              4=HEAVIER THAN AIR
            INCLUDE 'ATMOS.CMN'
  * C
  * C       ATMOS CONTAINS ALL PERTINENT DATA FOR CONCENTRATION
  * C       CALCULATIONS AND DETERMINATION OF SIGMA'S
  * C
  *         COMMON /ATMOS/ QRATE(100),USPEED,HEIGHT(100),SIGY,
  *        ZSIGZ,SIGTHETA,SIGPHI,XT,RT,HT,C,AO,XLS(100),
  *        ZELEVSOUR(100),XLID,WDIR,SX(100),SY(100),
  *        ZILAKE,IWCLASS2,NSOURCE
            DATA PI/3.14159265/
    C
    C        TEST FOR GRAVITY EFFECT
    C
            IF(IOPTION(5).NE.1) GO TO 10
            XDUM=X-XT
            YDUM=Y
            IF(IOPTION(2).EQ.1) CALL SIG1(XDUM,YDUM)
            IF(IOPTION(2).EQ.2) THEN
                        IF(ILAKE.EQ.1) THEN
                                CALL SIG2(XDUM,YDUM,IWCLASS2)
                             ELSE
                                CALL SIG2(XDUM,YDUM,IOPTION(3))
                                ENDIF
                        ENDIF
            IF(IOPTION(2).EQ.3) THEN
                        IF(ILAKE.EQ.1) THEN
                                CALL SIG3(XDUM,YDUM,IWCLASS2,IOPTION(4))
                             ELSE
                                CALL SIG3(XDUM,YDUM,IOPTION(3),IOPTION(4))
                                ENDIF
```

```
0025                     ENDIF
0026              SIGY=SIGY*SIGY+RT*RT/2.14/2.14
0027              SIGY=SQRT(SIGY)
0028              SIGZ=SIGZ*SIGZ+HT*HT/2.14/2.14
0029              SIGZ=SQRT(SIGZ)
0030              RETURN
0031         10   CONTINUE
          C
          C        TEST FOR BUILDING EFFECT
          C
0032              IF(IOPTION(6).NE.1) GO TO 20
0033              SIGY=SIGY*SIGY+C*AO/PI
0034              SIGY=SQRT(SIGY)
0035              SIGZ=SIGZ*SIGZ+C*AO/PI
0036              SIGZ=SQRT(SIGZ)
0037         20   CONTINUE
0038              RETURN
0039              END


PROGRAM SECTIONS

    Name                                          Bytes   Attributes

  0 $CODE                                           394   PIC CON REL LCL   SHR   EXE   RD
  2 $LOCAL                                          108   PIC CON REL LCL NOSHR NOEXE RD
  3 OPTIONS                                          48   PIC OVR REL GBL   SHR NOEXE   RD
  4 ATMOS                                          4908   PIC OVR REL GBL   SHR NOEXE   RD


ENTRY POINTS

    Address   Type   Name

  0-00000000         SIGADJ


VARIABLES

    Address   Type   Name                 Address   Type   Name              Address   Ty

  4-00000688   R*8   AO               4-00000680   R*8   C             4-00000678   R
  3-0000002C   I*4   IRUNCODE         4-00001324   I*4   IWCLASS2      4-00001328   I
  4-00000670   R*8   RT               4-00000660   R*8   SIGPHI        4-00000658   R
  4-00000650   R*8   SIGZ             4-00000320   R*8   USPEED        4-00000CD8   R
  2-00000008   R*8   XDUM             4-00000CD0   R*8   XLID          4-00000668   R
  2-00000010   R*8   YDUM
```

```
                                                                                  25-May-1983 17:0
                                                                                  24-May-1983 09:4
0001          SUBROUTINE SIMRAD(TT,SIGMAR,R)
        C     ********************************************
        C     TO CALCULATE (GIVEN TT) THE RADIUS OF CLOUD(R),AND SIGMAR(X)
        C
0002          REAL MASS
0003          INTEGER ZON,WIND
        C
0004          COMMON/BAT/SIGTH,SIGTV,SIG3H,SIG3V,CAY,TEMP
0005          COMMON/BBB/ZO,ZON,WIND,MASS,PI,UZC,RO,HO,VO,G,RHO,RHOA,VEL(4,6),
             *UZM,UAV,USTAR,XK,XL
        C
0006          SQDIFF=2.*CAY*SQRT(G*(RHO-RHOA)*VO/(PI*RHOA))*TT
0007          R=SQRT(SQDIFF+RO**2)
0008          SIGMAR=R/2.14
0009          RETURN
0010          END


PROGRAM SECTIONS

    Name                                               Bytes   Attributes

  0 $CODE                                                108   PIC CON REL LCL   SHR   EXE    R
  2 $LOCAL                                                 4   PIC CON REL LCL NOSHR NOEXE    R
  3 BAT                                                   24   PIC OVR REL GBL   SHR NOEXE    R
  4 BBB                                                  164   PIC OVR REL GBL   SHR NOEXE    R

ENTRY POINTS

    Address   Type  Name

  0-00000000        SIMRAD

VARIABLES

    Address   Type  Name                    Address   Type  Name                    Address   T

  3-00000010  R*4   CAY                   4-00000024  R*4   G                     4-0000001C
  4-00000010  R*4   PI                  AP-0000000C@  R*4   R                     4-00000018
  4-0000002C  R*4   RHOA                  3-00000008  R*4   SIG3H                 3-0000000C
  3-00000000  R*4   SIGTH                 3-00000004  R*4   SIGTV                 2-00000000
AP-00000004@  R*4   TT                    4-00000094  R*4   UAV                   4-00000098
  4-00000090  R*4   UZM                   4-00000020  R*4   VO                    4-00000008
  4-000000A0  R*4   XL                    4-00000000  R*4   ZO                    4-00000004

ARRAYS

    Address   Type  Name                                Bytes  Dimensions

  4-00000030  R*4   VEL                                    96  (4, 6)
```

```
          SUBROUTINE STAGE2(HALFHT)
    C     **************************
    C     THIS SUBROUTINE CORRESPONDS TO STAGE 2 OF THE CLOUD(S DISPERSION.
    C
          INTEGER A, ZON, WIND, CAT, PR
          REAL MASS
    C
          COMMON/BAT/SIGTH, SIGTV, SIG3H, SIG3V, CAY, TEMP
          COMMON/AAA/XS, XT, HT, XA, POPDIS(20, 20), TX, A, J, XGRID(80), SHINT, NINT
          COMMON/BBB/ZO, ZON, WIND, MASS, PI, UZC, RO, HO, VO, G, RHO, RHOA, VEL(4, 6),
         *UZM, UAV, USTAR, XK, XL
          COMMON/CCC/CAS(3, 12, 4, 6), P(12, 4, 6), MNO, CAT, ZM, TT, NST(50), TCEN(50)
          COMMON/EEE/HEIGHT(50), RADIUS(50), UVEL(50), TAU(50), CONC(50)
          COMMON/FFF/TA, TR, NVEL(6), NPOINT, NSEC, HTP, ALIM, NQ
          COMMON/GGG/NHAZ, NTYPE, NTIME(3), TOXIC(50, 3), TEXP(50, 3), HLEV(3),
         *TAW, EKONK, PR(3)
    C
          CALL SIMRAD(TT, SIGMAR, R)
          RADIUS(J)=R
          HEIGHT(J)=VO/PI/R/R
          SIGMAZ=HEIGHT(J)/2. 14
          HALFHT=HEIGHT(J)/2.
          IF(HALFHT. LE. ZO)RETURN
          UZC=USTAR*ALOG(HALFHT/ZO)/0. 4
          IF(J. EQ. NINT)GO TO 1
          UVEL(J+1)=UZC
        1 CONTINUE
          TX=2. *R/UZC/60.
          TAU(J)=TX
          CONC(J)=MASS/PI/SIGMAR/SIGMAZ/UZC
          IF(NTYPE. EQ. 1)CONC(J)=CONC(J)/TX/60.
          IF(NTYPE. EQ. 2)CONC(J)=CONC(J)*UZC/SIGMAR/SQRT(2. *PI)
          RETURN
          END
```

```
      SUBROUTINE STAGE3(HALFHT)
C     ***************************
C     THIS SUBROUTINE CORRESPONDS TO STAGE 3 OF THE CLOUD(S DISPERSION.
C
      INTEGER A,ZON,WIND,CAT,PR
      REAL MASS,IX
C
      COMMON/BAT/SIGTH,SIGTV,SIG3H,SIG3V,CAY,TEMP
      COMMON/AAA/XS,XT,HT,XA,POPDIS(20,20),TX,A,J,XGRID(80),SHINT,NINT
      COMMON/BBB/ZO,ZON,WIND,MASS,PI,UZC,RO,HO,VO,G,RHO,RHOA,VEL(4,6),
     *UZM,UAV,USTAR,XK,XL
      COMMON/CCC/CAS(3,12,4,6),P(12,4,6),MNO,CAT,ZM,TT,NST(50),TCEN(50)
      COMMON/EEE/HEIGHT(50),RADIUS(50),UVEL(50),TAU(50),CONC(50)
      COMMON/FFF/TA,TR,NVEL(6),NPOINT,NSEC,HTP,ALIM,NG
      COMMON/GGG/NHAZ,NTYPE,NTIME(3),TOXIC(50,3),TEXP(50,3),HLEV(3),
     *TAW,EKONK,PR(3)
C
      XV=EXP((J-1)*SHINT)-XS
      CALL FANDG(XV,SIGMAZ,6)
      SIGMAZ=SQRT(SIGMAZ**2/9.+SIGTV**2)
C
      CALL SIMRAD(TT,SIGMAR,R)
      RADIUS(J)=R
      HEIGHT(J)=2.14*SIGMAZ
      HALFHT=HEIGHT(J)/2.
      IF(HALFHT.LE.ZO)RETURN
      UZC=USTAR*ALOG(HALFHT/ZO)/0.4
      IX=MASS/PI/SIGMAR/SIGMAZ/UZC
      IF(NTYPE.EQ.2) IX=IX*UZC/SIGMAR/SQRT(2.*PI)
      IF(J.EQ.NINT)GO TO 1
      UVEL(J+1)=UZC
1     CONTINUE
      TX=4.28*SIGMAR/UZC/60.
      TAU(J)=TX
      CONC(J)=IX
      IF(NTYPE.EQ.1)CONC(J)=IX/TX/60.
      RETURN
      END
      SUBROUTINE STAGE4
C     ************************************************
C     THIS SUBROUTINE CORRESPONDS TO PASSIVE DIFFUSION OF THE CLOUD
C
      DIMENSION SIGMAY(6)
C
      INTEGER A,ZON,WIND,CAT,PR
      REAL MASS,IX
C
      COMMON/BAT/SIGTH,SIGTV,SIG3H,SIG3V,CAY,TEMP
      COMMON/AAA/XS,XT,HT,XA,POPDIS(20,20),TX,A,J,XGRID(80),SHINT,NINT
      COMMON/BBB/ZO,ZON,WIND,MASS,PI,UZC,RO,HO,VO,G,RHO,RHOA,VEL(4,6),
     *UZM,UAV,USTAR,XK,XL
      COMMON/CCC/CAS(3,12,4,6),P(12,4,6),MNO,CAT,ZM,TT,NST(50),TCEN(50)
      COMMON/EEE/HEIGHT(50),RADIUS(50),UVEL(50),TAU(50),CONC(50)
      COMMON/GGG/NHAZ,NTYPE,NTIME(3),TOXIC(50,3),TEXP(50,3),HLEV(3),
     *TAW,EKONK,PR(3)
C
      DATA SIGMAY/.22,.16,.11,.08,.06,.04/
C
      XV2=EXP((J-1)*SHINT)-XA
      CALL FANDG(XV2,SIGMAZ,A)
      SIGMAZ=SQRT(SIGMAZ**2+SIG3V**2)
      HEIGHT(J)=2.14*SIGMAZ
      UZC=USTAR*ALOG(HEIGHT(J)/2./ZO)/0.4
      IF(J.EQ.NINT)GO TO 1
      UVEL(J+1)=UZC
    1 CONTINUE
      AW=SIGMAY(A)*XV2/SQRT(1.+0.0001*XV2)
      SIGMAR=SQRT(AW**2+SIG3H**2)
      RADIUS(J)=2.14*SIGMAR
      IX=MASS/PI/SIGMAR/SIGMAZ/UZC
      IF(NTYPE.EQ.2) IX=IX*UZC/SIGMAR/SQRT(2.*PI)
      TX=4.28*SIGMAR/UZC/60.
      TAU(J)=TX
      CONC(J)=IX
      IF(NTYPE.EQ.1)CONC(J)=IX/TX/60.
      RETURN
      END
```

```
                                                              25-May-1983 17:05:
                                                              19-May-1983 14:15:

            SUBROUTINE SUMMAT
            IMPLICIT REAL*8 (A-H,O-Z)
      C
      C      ROUTINE CALCULATES OVERALL CONSEQUENCE CURVE OF ALL CASES
      C
            INCLUDE 'LINKUP.CMN'
    *       COMMON /LINKUP/ PERC(10),FIXJ(1000,10),PROB(10),
    *      ZCLT(10,10),TCLT(10,10),PK(10),PJGRID(10),PJ(10),
    *      ZGRIDFAT(1000,10),ZNU(10),PROBJ(1000),J1
    * C
    * C      CONCENTRATION LETHAL DOSE = CLT
    * C      EXPOSURE TIMES FOR CLT    = TCLT
    * C
      C
      C      LOOP THROUGH ALL CASES
      C
            DO 30 ICASE=1,1000
            IF(PROBJ(ICASE).LE.0.) GO TO 31
      C
      C      LOOP THROUGH EACH ZNU
      C
            DO 11 INU=1,10
            IF(ZNU(INU).LE.0.) GO TO 12
      C
      C      FIND INTERPOLATION BOUNDS AND TEST ENDS
      C
            IF(ICASE.EQ.1) PROB(INU)=0.
            IF(ZNU(INU).LE.GRIDFAT(ICASE,1)) THEN
                        PROB(INU)=PROB(INU)+PJ(1)*PROBJ(ICASE)
                        GO TO 11
                        ENDIF
            IF(ZNU(INU).GE.GRIDFAT(ICASE,J1)) THEN
                        PROB(INU)=PROB(INU)+PJ(J1)*PROBJ(ICASE)
                        GO TO 11
                        ENDIF
            DO 20 II=2,J1-1
            IF(ZNU(INU).LE.GRIDFAT(ICASE,II)) GO TO 21
         20 CONTINUE
         21 CONTINUE
            PROB(INU)=PROB(INU)+PROBJ(ICASE)*
           Z(PJ(II-1)+(PJ(II)-PJ(II-1))/
           Z(GRIDFAT(ICASE,II)-GRIDFAT(ICASE,II-1))*
           Z(ZNU(INU)-GRIDFAT(ICASE,II-1)))
         11 CONTINUE
         12 CONTINUE
      C
      C      NOW HAVE PROB(INU) VS ZNU(INU) FOR DISPERSION CASES
      C
         30 CONTINUE
         31 CONTINUE
            RETURN
            END
      C
      C      TERR COMPUTES ANY TERRAIN MODIFICATION
      C       TO THE EFFECTIVE RELEASE HEIGHT H
      C
            SUBROUTINE TERR(ISOURCE)
            IMPLICIT REAL*8 (A-H,O-Z)
            INCLUDE 'OPTIONS.CMN'
    * C
    * C      OPTIONS CONTAIN ALL OPTIONS REQUIRED FOR EXECUTION
    * C
    *       COMMON /OPTIONS/ IOPTION(11),IRUNCODE
    * C      IOPTION IS DEFINED AS FOLLOWS :
    * C                 IOPTION(1)  : PLUME MODEL=1; PUFF .NE. 1; IN/OUTDOOR=3
    * C                 IOPTION(2)  : SIGMA Y,Z OPTIONS 1,2,OR 3
    * C                 IOPTION(3)  : WEATHER CLASS (1=A,2=B,...6=F)
    * C                 IOPTION(4)  : TERRAIN ROUGHNESS(1,2,...6)
    * C                 IOPTION(5)  : GRAVITY EFFECT OPTION (1=INCLUDE)
    * C                 IOPTION(6)  : BUILDING EFFECT OPTION (1=INCLUDE)
    * C                 IOPTION(7)  : TERRAIN MODIFICATION (1=INCLUDE)
    * C                 IOPTION(8)  : TRAPPING OPTION (1=INCLUDE)
    * C                 IOPTION(9)  : LAKE BREEZE EFFECT (1=INCLUDE)
    * C                 IOPTION(10) : DEBUGGING SWITCH 1= ADDITIONAL OUTPUT
    * C                                                2= TERRAIN PLOT PRODUCED
    * C                 IOPTION(11) : RELEASE TYPE 1=PASSIVE
    * C                                            2=VERTICAL JET
    * C                                            3=FLARE
                                                   4=HEAVIER THAN AIR
            INCLUDE 'PARA.CMN'
    * C      COMMON PARA IS THE MAIN PARAMETER BLOCK
    * C      -CGX,CGY ARE THE LOCATIONS OF THE CG OF
    * C       THE AREA BEING REPRESENTED
    * C      -POP IS THE POPULATION REPRESENTED AT THE CG (IN # OF PEOPLE)
    * C      -AREA IS THE AREA OF THE REPRESENTED ELEMENT OF TERRAIN(KM**2)
    * C      -ELEV IS ELEVATION OF AREA
    * C      -H IS THE EFFECTIVE RELEASE HEIGHT
    * C      -XCORD,YCORD ARE THE COMPONENTS FOR THE CONCENTRATION CALC
    * C
    *       COMMON /PARA/ CGX(1000),CGY(1000),AREA(1000),POP(1000)
    *      Z,ELEV(1000),NP,H(1000),CONC(1000),XCORD(1000),YCORD(1000)
            INCLUDE 'ATMOS.CMN'
    * C
    * C      ATMOS CONTAINS ALL PERTINENT DATA FOR CONCENTRATION
    * C      CALCULATIONS AND DETERMINATION OF SIGMA'S
    * C
    *       COMMON /ATMOS/ GRATE(100),USPEED,HEIGHT(100),SIGY,
    *      ZSIGZ,SIGTHETA,SIGPHI,XT,RT,HT,C,AO,XLS(100),
    *      ZELEVSOUR(100),XLID,WDIR,SX(100),SY(100),
    *      ZILAKE,IWCLASS2,NSOURCE
            IF(IOPTION(7).NE.1.OR.IOPTION(3).LE.4) THEN
                      DO 10 I=1,NP
                      H(I)=HEIGHT(ISOURCE)
       10             CONTINUE
                  ELSE
                      DO 20 I=1,NP
                      H(I)=HEIGHT(ISOURCE)-(ELEV(I)-ELEVSOUR(ISOURCE))
                      IF(H(I).LT.10.) THEN
                      WRITE(1,21) I
```

```
0018        21                 FORMAT('*** EFFECTIVE RELEASE HEIGHT FOR '
                  Z            'ELEMENT NO. ',I5,/,' WAS FOUND TO BE LESS THAN ',
                  Z            '10. METRES,- HEIGHT HAS BEEN SET TO 10. M')
0019                           H(I)=10.
0020                           ENDIF
0021        20                 CONTINUE
0022                           ENDIF
0023                RETURN
0024                END


PROGRAM SECTIONS

    Name                                      Bytes   Attributes

  0 $CODE                                       191   PIC CON REL LCL   SHR   EXE   RD
  1 $PDATA                                      124   PIC CON REL LCL   SHR NOEXE   RD
  2 $LOCAL                                       12   PIC CON REL LCL NOSHR NOEXE   RD
  3 OPTIONS                                      48   PIC OVR REL GBL   SHR NOEXE   RD
  4 PARA                                      72004   PIC OVR REL GBL   SHR NOEXE   RD
  5 ATMOS                                      4908   PIC OVR REL GBL   SHR NOEXE   RD

ENTRY POINTS

    Address   Type  Name

  0-00000000        TERR

VARIABLES

    Address   Type  Name                 Address   Type  Name                  Address   Typ

  5-00000688  R*8   AO                 5-00000680  R*8   C                   5-00000678  R*
  5-00001320  I*4   ILAKE              3-0000002C  I*4   IRUNCODE           AP-00000004@ I*
  4-00009C40  I*4   NP                 5-00001328  I*4   NSOURCE             5-00000670  R*
  5-00000658  R*8   SIGTHETA           5-00000648  R*8   SIGY                5-00000650  R*
  5-00000CD8  R*8   WDIR               5-00000CD0  R*8   XLID                5-00000668  R*

ARRAYS

    Address   Type  Name                        Bytes  Dimensions

  4-00003E80  R*8   AREA                         8000  (1000)
  4-00000000  R*8   CGX                          8000  (1000)
  4-00001F40  R*8   CGY                          8000  (1000)
  4-0000BB84  R*8   CONC                         8000  (1000)
  4-00007D00  R*8   ELEV                         8000  (1000)
  5-000009B0  R*8   ELEVSOUR                      800  (100)
  4-00009C44  R*8   H                            8000  (1000)
  5-00000328  R*8   HEIGHT                        800  (100)
  3-00000000  I*4   IOPTION                        44  (11)
  4-00005DC0  R*8   POP                          8000  (1000)
```

```
      SUBROUTINE TRANS
C     ************************
C     THIS SUBROUTINE CALCULATES THE TRANSITION
C     POINT BETWEEN STAGES 3 AND 4
C
      DIMENSION S(10)
C
      REAL MASS
      INTEGER A, CAT, ZON, WIND
C
      COMMON/BAT/SIGTH, SIGTV, SIG3H, SIG3V, CAY, TEMP
      COMMON/AAA/XS, XT, HT, XA, POPDIS(20, 20), TX, A, J, XGRID(80), SHINT, NINT
      COMMON/BBB/ZO, ZON, WIND, MASS, PI, UZC, RO, HO, VO, G, RHO, RHOA, VEL(4, 6),
     *UZM, UAV, USTAR, XK, XL
      COMMON/CCC/CAS(3, 12, 4, 6), P(12, 4, 6), MNO, CAT, ZM, TTT, NST(50), TCEN(50)
      COMMON/EEE/HEIGHT(50), RADIUS(50), UVEL(50), TAU(50), CONC(50)
      COMMON/FFF/TA, TR, NVEL(6), NPOINT, NSEC, HTP, ALIM, NQ
      COMMON/EXTRA/AMASS, ARE, NFN, NHEAT, TEK(80), ROA(80), HRATE(80), CMASS,
     *NRANGE, DELRHO(80), AIRM(80), VELRAT(80), RICH(80), NENT
      COMMON/XYZ/NWRITE
C
      S(1)=0.0
      S(2)=XA
      S(3)=10
      S(4)=(XL-XK)/10.
    5 CALL ROOT1(S)
      IF(S(1))1, 2, 3
    1 XA=XK
      GO TO 4
    2 CONTINUE
      XA=S(2)
      GO TO 4
    3 XQ=S(2)
      TTT=TCEN(J-1)+(XQ-XL)/UVEL(J)
      XQS=XQ-XS
      CALL FANDG(XQS, SIGMAZ, 6)
      SIGMAZ=SQRT(SIGMAZ**2/9.+SIGTV**2)
      CALL SIMRAD(TTT, SIGMAR, R)
      CVOL=PI*R*R*2.14*SIGMAZ
C     TOTAL CLOUD VOLUME
      CEXVOL=CVOL-VO
C     INCREASE IN CLOUD VOLUME FROM TIME OF FORMATION OF SOURCE CYLINDER
      CMASS=CEXVOL*RHOA+AMASS
C     MASS OF AIR IN CLOUD
      CMS=MASS+CMASS
C     TOTAL CLOUD MASS
      RHOC=CMS/CVOL
C     CLOUD DENSITY
      RDIFF=RHOC-RHOA
      S(3)=RDIFF-ALIM
      GO TO 5
    4 CONTINUE
      RP=XA-XL
      IF(RP)8, 9, 9
    8 XA=XL
    9 CONTINUE
      XG=XA-XS
```

```
0045            CALL SIMRAD(TA,SIG3H,R3)
0046            CALL FANDG(XG,SG,6)
0047            SIG3V=SQRT(SG**2/9.+SIGTV**2)
0048            RETURN
0049            END



PROGRAM SECTIONS

    Name                                        Bytes   Attributes

  0 $CODE                                         422   PIC CON REL LCL   SHR   EXE   RD
  1 $PDATA                                          4   PIC CON REL LCL   SHR NOEXE   RD
  2 $LOCAL                                        168   PIC CON REL LCL NOSHR NOEXE   RD
  3 BAT                                            24   PIC OVR REL GBL   SHR NOEXE   RD
  4 AAA                                          1956   PIC OVR REL GBL   SHR NOEXE   RD
  5 BBB                                           164   PIC OVR REL GBL   SHR NOEXE   RD
  6 CCC                                          5024   PIC OVR REL GBL   SHR NOEXE   RD
  7 EEE                                          1000   PIC OVR REL GBL   SHR NOEXE   RD
  8 FFF                                            52   PIC OVR REL GBL   SHR NOEXE   RD
  9 EXTRA                                        2268   PIC OVR REL GBL   SHR NOEXE   RD
 10 XYZ                                             4   PIC OVR REL GBL   SHR NOEXE   RD

ENTRY POINTS

    Address   Type  Name

  0-00000000        TRANS

VARIABLES

    Address   Type  Name                Address   Type  Name                 Address   Typ

  4-00000654  I*4   A                8-0000002C  R*4   ALIM              9-00000000  R*
  6-00001204  I*4   CAT              3-00000010  R*4   CAY               2-00000040  R*
  2-00000044  R*4   CMS              2-0000003C  R*4   CVOL              5-00000024  R*
  4-00000008  R*4   HT               8-00000028  R*4   HTP               4-00000658  I*
  6-00001200  I*4   MNO              9-000008D8  I*4   NENT              9-00000008  I*
  4-000007A0  I*4   NINT             8-00000020  I*4   NPOINT            8-00000030  I*
  8-00000024  I*4   NSEC            10-00000000  I*4   NWRITE            5-00000010  R*
  5-00000018  R*4   RO               2-00000058  R*4   R3                2-0000004C  R*
  5-0000002C  R*4   RHOA             2-00000048  R*4   RHOC              2-00000050  R*
  4-0000079C  R*4   SHINT            3-00000008  R*4   SIG3H             3-0000000C  R*
  2-00000030  R*4   SIGMAZ           3-00000000  R*4   SIGTH             3-00000004  R*
  3-00000014  R*4   TEMP             8-00000004  R*4   TR                6-0000120C  R*
  5-00000094  R*4   UAV              5-00000098  R*4   USTAR             5-00000014  R*
  5-00000020  R*4   VO               5-00000008  I*4   WIND              4-0000000C  R*
  5-0000009C  R*4   XK               5-000000A0  R*4   XL                2-00000028  R*
  4-00000000  R*4   XS               4-00000004  R*4   XT                5-00000000  R*
  6-00001208  R*4   ZM
```

```
      C
      C      TRAP CALCULATES THE TERM APPLICABLE
      C       TO THE TRAPPING OPTION
      C
            FUNCTION TRAP(I)
            IMPLICIT REAL*8 (A-H,O-Z)
            INCLUDE 'ATMOS.CMN'
    * C
    * C     ATMOS CONTAINS ALL PERTINENT DATA FOR CONCENTRATION
    * C     CALCULATIONS AND DETERMINATION OF SIGMA'S
    * C
    *       COMMON /ATMOS/ QRATE(100),USPEED,HEIGHT(100),SIGY,
    *      ZSIGZ,SIGTHETA,SIGPHI,XT,RT,HT,C,AO,XLS(100),
    *      ZELEVSOUR(100),XLID,WDIR,SX(100),SY(100),
    *      ZILAKE,IWCLASS2,NSOURCE
            INCLUDE 'PARA.CMN'
    * C      COMMON PARA IS THE MAIN PARAMETER BLOCK
    * C      -CGX,CGY ARE THE LOCATIONS OF THE CG OF
    * C       THE AREA BEING REPRESENTED
    * C      -POP IS THE POPULATION REPRESENTED AT THE CG (IN # OF PEOPLE)
    * C      -AREA IS THE AREA OF THE REPRESENTED ELEMENT OF TERRAIN(KM**2)
    * C      -ELEV IS ELEVATION OF AREA
    * C      -H IS THE EFFECTIVE RELEASE HEIGHT
    * C      -XCORD,YCORD ARE THE COMPONENTS FOR THE CONCENTRATION CALC
    * C
    *       COMMON /PARA/ CGX(1000),CGY(1000),AREA(1000),POP(1000)
    *      Z,ELEV(1000),NP,H(1000),CONC(1000),XCORD(1000),YCORD(1000)
            INCLUDE 'OPTIONS.CMN'
    * C
    * C      OPTIONS CONTAIN ALL OPTIONS REQUIRED FOR EXECUTION
    * C
    *       COMMON /OPTIONS/ IOPTION(11),IRUNCODE
    * C       IOPTION IS DEFINED AS FOLLOWS :
    * C                     IOPTION(1)  : PLUME MODEL=1; PUFF .NE.1; IN/OUTDOOR=3
    * C                     IOPTION(2)  : SIGMA Y,Z OPTIONS 1,2,OR 3
    * C                     IOPTION(3)  : WEATHER CLASS (1=A,2=B,...6=F)
    * C                     IOPTION(4)  : TERRAIN ROUGHNESS(1,2,...6)
    * C                     IOPTION(5)  : GRAVITY EFFECT OPTION (1=INCLUDE)
    * C                     IOPTION(6)  : BUILDING EFFECT OPTION (1=INCLUDE)
    * C                     IOPTION(7)  : TERRAIN MODIFICATION (1=INCLUDE)
    * C                     IOPTION(8)  : TRAPPING OPTION (1=INCLUDE)
    * C                     IOPTION(9)  : LAKE BREEZE EFFECT (1=INCLUDE)
    * C                     IOPTION(10) : DEBUGGING SWITCH 1= ADDITIONAL OUTPUT
    * C                                                    2= TERRAIN PLOT PRODUCEI
    * C
    * C                     IOPTION(11) : RELEASE TYPE 1=PASSIVE
    * C                                                2=VERTICAL JET
    * C                                                3=FLARE
    * C                                                4=HEAVIER THAN AIR
    * C
              TRAP=0.
              IF(IOPTION(8).NE.1) GO TO 10
              DO 20 N=1,4
              TRAP=TRAP+EXP(-0.5*((H(I)+2.*FLOAT(N)*XLID)/SIGZ)**2)
              TRAP=TRAP+EXP(-0.5*((H(I)-2.*FLOAT(N)*XLID)/SIGZ)**2)
         20   CONTINUE
         10   CONTINUE
              TRAP=TRAP+EXP(-0.5*H(I)*H(I)/SIGZ/SIGZ)
              RETURN
              SUBROUTINE VJET(ISOURCE)
              IMPLICIT REAL*8 (A-H,O-Z)
        C
        C      ROUTINE TO CALCULATE MODIFICATIONS DUE TO
        C      VERTICAL JET EFFECTS
        C
              INCLUDE 'OPTIONS.CMN'
      * C
      * C      OPTIONS CONTAIN ALL OPTIONS REQUIRED FOR EXECUTION
      * C
      *       COMMON /OPTIONS/ IOPTION(11),IRUNCODE
      * C      IOPTION IS DEFINED AS FOLLOWS :
      * C                 IOPTION(1)  : PLUME MODEL=1; PUFF .NE. 1; IN/OUTDOOR=3
      * C                 IOPTION(2)  : SIGMA Y,Z OPTIONS 1,2,OR 3
      * C                 IOPTION(3)  : WEATHER CLASS (1=A,2=B,...6=F)
      * C                 IOPTION(4)  : TERRAIN ROUGHNESS(1,2,...6)
      * C                 IOPTION(5)  : GRAVITY EFFECT OPTION (1=INCLUDE)
      * C                 IOPTION(6)  : BUILDING EFFECT OPTION (1=INCLUDE)
      * C                 IOPTION(7)  : TERRAIN MODIFICATION (1=INCLUDE)
      * C                 IOPTION(8)  : TRAPPING OPTION (1=INCLUDE)
      * C                 IOPTION(9)  : LAKE BREEZE EFFECT (1=INCLUDE)
      * C                 IOPTION(10) : DEBUGGING SWITCH 1= ADDITIONAL OUTPUT
      * C                                                2= TERRAIN PLOT PRODUCEI
      * C                 IOPTION(11) : RELEASE TYPE 1=PASSIVE
      * C                                            2=VERTICAL JET
      * C                                            3=FLARE
      * C                                            4=HEAVIER THAN AIR
              INCLUDE 'RELTYPE.CMN'
      *       COMMON /RELTYPE/ DISCH(100),WO,SO2FLOW(100),DTHDZ,ALPHA,
      *      ZU10,CFLARE,AMTEMP
              INCLUDE 'ATMOS.CMN'
      * C
      * C      ATMOS CONTAINS ALL PERTINENT DATA FOR CONCENTRATION
      * C      CALCULATIONS AND DETERMINATION OF SIGMA'S
      * C
      *       COMMON /ATMOS/ QRATE(100),USPEED,HEIGHT(100),SIGY,
      *      ZSIGZ,SIGTHETA,SIGPHI,XT,RT,HT,C,AO,XLS(100),
      *      ZELEVSOUR(100),XLID,WDIR,SX(100),SY(100),
      *      ZILAKE,IWCLASS2,NSOURCE
              INCLUDE 'DISPD.CMN'
      * C      FACTORS FOR DISPERSION COEFFICIENTS
      * C
      * C   AA1,AA2,BB1,BB2,CC3 ARE FUNCTION OF WEATHER CLASS
      * C   CC1,CC2,DD1,DD2,     ARE FUNCTIONS OF ROUGHNESS
      * C
      *       COMMON/DISPD/ AA1(6),AA2(6),BB1(6),BB2(6),CC1(6)
      *      1,CC2(6),CC3(6),DD1(6),DD2(6),ZO(6)
              IF(IOPTION(3).LE.4) THEN
                          U=0.5
                          IF(USPEED.GT.0.5) U=USPEED
                          DELH=3.*DISCH(ISOURCE)*(WO/U-1.)
                        ELSE
                          S=9.8/AMTEMP*DTHDZ
                          M=WO*WO*DISCH(ISOURCE)*DISCH(ISOURCE)/4.
                          IF(USPEED.GT.0.5) THEN
                                    DELH=1.5*(M/USPEED)**0.33333
             Z                            /S**0.16666
```

```
                                   ELSE
                                      DELH=2.44*(M/S)**0.25
                                      ENDIF
                           ENDIF
        HEIGHT(ISOURCE)=HEIGHT(ISOURCE)+DELH
C
C        ADJUST USPEED TO EFFECTIVE STACK HEIGHT
C
        IF(HEIGHT(ISOURCE).LE.10.) GO TO 12
        IF(HEIGHT(ISOURCE).LE.50.) THEN
                                 USTAR=U10*0.4/LOG(10./ZO(IOPTION(4)))
                                 USPEED=USTAR/0.4*LOG(HEIGHT(ISOURCE)
     Z                                 /ZO(IOPTION(4)))
                              ELSE
                                 USPEED=U10*(HEIGHT(ISOURCE)/10.)**ALPHA
                              ENDIF
   12   CONTINUE
        RETURN
        END
```

```
PROGRAM SECTIONS

    Name                                          Bytes   Attributes

  0 $CODE                                           450   PIC CON REL LCL   SHR   EXE   R
  2 $LOCAL                                           44   PIC CON REL LCL NOSHR NOEXE   R
  3 OPTIONS                                          48   PIC OVR REL GBL   SHR NOEXE   R
  4 RELTYPE                                        1648   PIC OVR REL GBL   SHR NOEXE   R
  5 ATMOS                                          4908   PIC OVR REL GBL   SHR NOEXE   R
  6 DISPD                                           480   PIC OVR REL GBL   SHR NOEXE   R

ENTRY POINTS

    Address   Type  Name

  0-00000000        VJET

VARIABLES

    Address   Type  Name                 Address   Type  Name                  Address   T

  5-00000688  R*8   A0                 4-00000650  R*8   ALPHA               4-00000668  R
  4-00000660  R*8   CFLARE             2-00000008  R*8   DELH                4-00000648  R
  5-00001320  I*4   ILAKE              3-0000002C  I*4   IRUNCODE           AP-00000004@ I
  2-00000020  I*4   M                  5-00001328  I*4   NSOURCE             5-00000670  R
  5-00000660  R*8   SIGPHI             5-00000658  R*8   SIGTHETA            5-00000648  R
  2-00000000  R*8   U                  4-00000658  R*8   U10                 5-00000320  R
  4-00000320  R*8   W0                 5-00000CD8  R*8   WDIR                5-00000CD0  R
```

25-May-1983 17:04
24-May-1983 09:52

```
      FUNCTION XBE(I,XIC)
      IMPLICIT REAL*8 (A-H,O-Z)
C
C
C      THIS ROUTINE USES A NEWTON-RAPHSON TECHNIQUE TO
C          FIND THE ROOT OF AN EQUATION
C          THE CONVERGENCE IS SECOND ORDER
C          THE EQUATION IS ADDED AS A SEPARATE FUNCTION 'EQN'
C          THE ROUTINE USES A BEST GUESS OF XI=100. M
C          THE INITIAL INCREMENT IS SET AT .1*XI
C
C
      IWHAT=0
      XI=100.
      DELX=0.1*XI
  999 CONTINUE
      XINEW=XI+DELX
      IWHAT=IWHAT+1
      EQNX=EQN(XI,I,XIC)
      FPRIME=(EQN(XINEW,I,XIC)-EQNX)/DELX
      XIOLD=XI
      XI=XI-EQNX/FPRIME
      DELX=ABS(XIOLD-XI)
      XBE=XI
      IF(ABS(XIOLD).LT.1.E-5) XIOLD=1.E-5
      IF((DELX/XIOLD).LT.1.E-05) RETURN
      IF(IWHAT.GT.25) THEN
              STOP ' ITERATION FAILURE IN SUBROUTINE XBE'
              ENDIF
      GO TO 999
      END
```

```
        C
                  FUNCTION XOFUNC(I,XEOUT)
                  IMPLICIT REAL*8 (A-H,O-Z)
                  INCLUDE 'PARA.CMN'
      * C          COMMON PARA IS THE MAIN PARAMETER BLOCK
      * C          -CGX,CGY ARE THE LOCATIONS OF THE CG OF
      * C           THE AREA BEING REPRESENTED
      * C          -POP IS THE POPULATION REPRESENTED AT THE CG (IN # OF PEOPLE)
      * C          -AREA IS THE AREA OF THE REPRESENTED ELEMENT OF TERRAIN(KM**2)
      * C          -ELEV IS ELEVATION OF AREA
      * C          -H IS THE EFFECTIVE RELEASE HEIGHT
      * C          -XCORD,YCORD ARE THE COMPONENTS FOR THE CONCENTRATION CALC
      * C
      *           COMMON /PARA/ CGX(1000),CGY(1000),AREA(1000),POP(1000)
      *          Z,ELEV(1000),NP,H(1000),CONC(1000),XCORD(1000),YCORD(1000)
                  INCLUDE 'ATMOS.CMN'
      * C
      * C         ATMOS CONTAINS ALL PERTINENT DATA FOR CONCENTRATION
      * C         CALCULATIONS AND DETERMINATION OF SIGMA'S
      * C
      *           COMMON /ATMOS/ QRATE(100),USPEED,HEIGHT(100),SIGY,
      *          ZSIGZ,SIGTHETA,SIGPHI,XT,RT,HT,C,AO,XLS(100),
      *          ZELEVSOUR(100),XLID,WDIR,SX(100),SY(100),
      *          ZILAKE,IWCLASS2,NSOURCE
                  ILAKE=1
                  CALL SIG(XEOUT,YCORD(I))
                  ILAKE=0
                  SIGUXE=SIGY
                  CALL SIG(XEOUT,YCORD(I))
                  SIGYF=SIGY+H(I)/8.
                  XOFUNC=XEOUT-XEOUT*SIGYF/SIGUXE
                  RETURN
                  END
```

# APPENDIX B

# SUBROUTINE ABSTRACTS

| SUBROUTINE | DESCRIPTION |
|---|---|
| ACCUMMU | -Accumulates the concentration at each location for each case in the run. |
| CG | -Calculates the center of gravity of each redefined location area. |
| CONVERT | -Calculates the x and y coordinates relative to the source origin and wind direction for use in the dispersion calculation routines. |
| DIVIS | -Subdivides terrain input into required number of grid point locations for desired terrain definition. |
| DOCOUT | -Dumps location concentrations after each case has been calculated, including the cumulative case, to a print file. |
| EQN2 | -Function routine for probability calculation. |
| FSIMP | -Simpson's Rule integration routine. |
| GAM | -Polynonial fit of Gamma Function $\Gamma$ (x). |
| INDOOR | -attenuates the Puff model by the Indoor/outdoor effect. |
| INPUTC | -Reads necessary data for next case. Only accepts 10 cases per run. |

| SUBROUTINE | DESCRIPTION |
|---|---|
| INPUTP | -Reads required probabilisitc data from file 'PROBCON.DAT' |
| INPUTR | -Reads atmospheric data which is fixed for the entire run and any calculation options not dependent on each specific case. Contains some diagnostics of input data. |
| INPUTT | -Generates terrain data from file 'TERRAIN.DAT', calls DIVIS to subdivide data into a finer grid for internal processing. |
| INTEGRAL | -Functions to return integral of probability distribution defined by LAKE. |
| LAKE | -Calculates lake breeze effect according to a 3-stage model. |
| LINK | -Calculates values of $P_k$, the probability of K% of the population being affected. Interpolation is made between the $P_k$ array to find probability function for fixed reference points and then summed over entire affected terrain weighed by the population density. This is done for each case such that $P_J$ represents the probability function of fatalities over terrain map for each dispersion condition. |

| SUBROUTINE | DESCRIPTION |
|---|---|
| MAIN | -Mainline of code, opens file storage, calls all primary execution routines. |
| OUTPUT | -Routine to dump a listing of terrain data for debugging purposes. |
| PLUME | -Calculates the concentrations of release at each location assuming a plume model of dispersion. |
| PROBOUT | -Lists the 'overall consequence of release' function. |
| PUFF | -Calculates the maximum concentration at each location assuming a puff model, up to 100 discreet puffs can be used to simulate each release case. |
| RISK | -Modified version of H2SRISK, used to calculate probabilites of exceeding $x_t$. |
| ROOT | -Calculation routine to find roots using Newton Raphson method. |
| SIG,SIG1,SIG2,SIG3 | -Calculation of the dispersion coefficients $\sigma y$, $\sigma z$ according to 3 options, default, Brigg's, or Hosker. |
| SIGADJ | -Modifies dispersion coefficients to account for gravity effect or building downwash. |

| SUBROUTINE | DESCRIPTION |
|---|---|
| SUMMAT | -Sums consequence of different dispersion conditions into overall consequence of postulated $H_2S$ release. |
| TERR | -Computes a terrain modification to the effective release height. |
| TRAP | -Computes the height term of the dispersion calculation and, if required, calculates trapping effect. |
| XBE,EQN, BOUNDL | -Functions which return values of $X_B$ and $X_E$ required by LAKE. |
| XOFUNC | -Function to return position of virtual source required by LAKE. |

## SUBROUTINE ABSTRACT

NAME OF SUBROUTINE: ACCUMMU

FUNCTION OF SUBROUTINE: - accumulates the concentration from each source for a total concentration to be applied to each dispersion case.

INPUT: ISOURCE, CONC, NSOURCE

OUTPUT: ACCUM, CONC

DESCRIPTION:

- called by MAIN after the concentrations have been determined for each source.
- for each grid point i, ACCUM (i) stores the cumulative concentration for each source.
- if ISOURCE = NSOURCE, all sources have been considered and CONC is set equal to ACCUM to continue to the RISK consequence analysis, and ACCUM is zeroed for next dispersion case.

## SUBROUTINE ABSTRACT

NAME OF SUBROUTINE: BOUNDL

FUNCTION OF SUBROUTINE: - returns the height of the Thermal Internal Boundary Layer for a given value of x.

INPUT: x

OUTPUT: L (x)

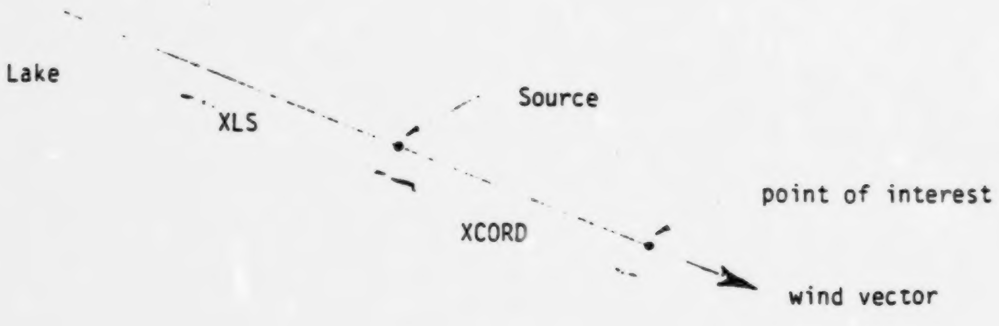
DESCRIPTION:

- the value of x is the distance measured from the lake along the axis of wind.

  i.e. $x = XCORD(I) + XLS\ (ISOURCE)$

- at present a simple curve fit is used as a default

$$L(x) = -0.0555x + 10.555x^{\frac{1}{2}}$$


Lake
XLS
Source
XCORD
point of interest
wind vector

# SUBROUTINE ABSTRACT

NAME OF SUBROUTINE: CG

FUNCTION OF SUBROUTINE: - calculate the centre of area for each terrain element from DIVIS

INPUT: NEWNODE, XNEW, YNEW

OUTPUT: CGX, CGY

DESCRIPTION:

- the routine calculates the centre of the element simply as the average value of the corner coordinates,

$$\text{eg.} \quad CGX = \frac{\sum_{j=1}^{4} XNEW(i,j)}{4}$$

## SUBROUTINE ABSTRACT

NAME OF SUBROUTINE: CONVERT

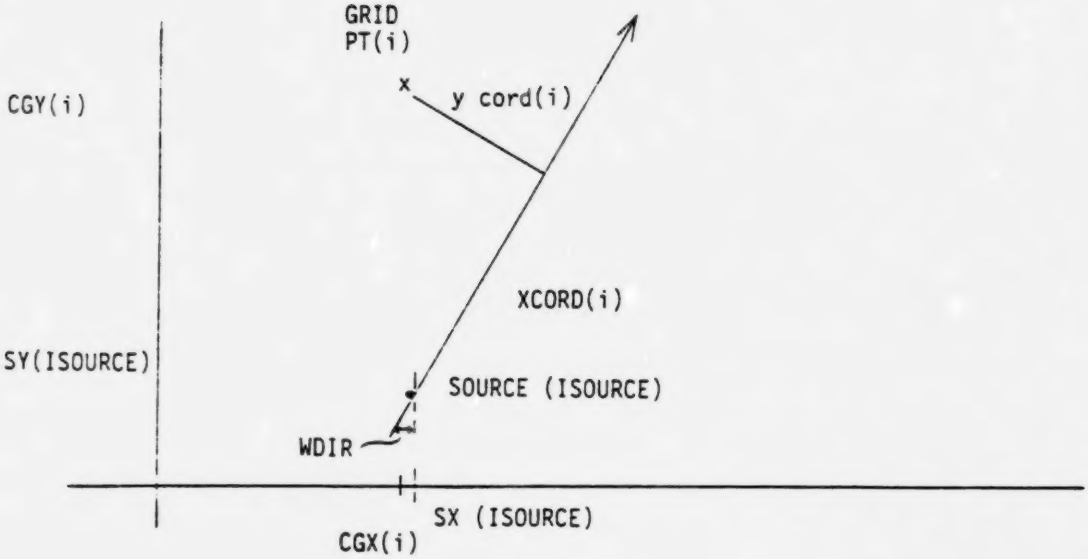
FUNCTION OF SUBROUTINE: - calculates the X & Y coordinates of each grid point with respect to the wind direction and location of the source.

INPUT: CGX, CGY, SX, SY, WDIR

OUTPUT: XCORD, YCORD

DESCRIPTION:

- called by MAIN for every source
- the CGs of each grid point are used to calculate the x and y coordinates relative to the source, located at SX, and SY, and along the axis of the wind.


GRID
PT(i)
x
y cord(i)
CGY(i)
XCORD(i)
SY(ISOURCE)
SOURCE (ISOURCE)
WDIR
SX (ISOURCE)
CGX(i)

# SUBROUTINE ABSTRACT

NAME OF SUBROUTINE: DIVIS

FUNCTION OF SUBROUTINE: - subdivide terrain elements for increased site definition and reduced data input

INPUT: NELM, X, Y, POPDENS, ELEVOLD, IDIV

OUTPUT: NEWNODE, XNEW, YNEW, NEWFROM

DESCRIPTION:

- Monserco library routine
- performs the re-definition of terrain grid based on the array IDIV
- provides required input to routine CG
- calculates the area of each terrain element and calculates the population from the population density, if required.
- the area of the general quadrilateral terrain element is determined
- variables are defined as follows;

NELM - original element definition
X,Y - original coordinate definition array
POPDENS - population density array
ELEVOLD - element elevation array
NEWNODE, XNEW, YNEW - internal node definition and coordinate arrays
NEWFROM - pointer array relating original grid elements to internal definition

## SUBROUTINE ABSTRACT

NAME OF SUBROUTINE: DOCOUT

FUNCTION OF SUBROUTINE: - Dumps concentration at each grid point for every source, and cumulative concentrations.

INPUT: CONC, ISOURCE, NSOURCE, ICASE

OUTPUT: LIST FILE 'GASPROB.LIS'

DESCRIPTION:

N/A

## SUBROUTINE ABSTRACT

NAME OF SUBROUTINE: EQN

FUNCTION OF SUBROUTINE: - calculation of lakebreeze function for input to XBE for determination of $X_B$ & $X_E$ for LAKE

INPUT: XIC, I, BOUNDL, SIG

OUTPUT: if XIC <0 $X_E$

if XIC >0 $X_B$

DESCRIPTION:

provides the value of the following equation,

$$EQN = L (X_{BE}) - H(i) + 2.5*XIC* \sigma_z (X_{BE})$$

where L is the boundary layer height

# SUBROUTINE ABSTRACT

NAME OF SUBROUTINE: EQN2

FUNCTION OF SUBROUTINE: - evaluate function for root determination for routines ROOT and RISK

INPUT: x, COV

OUTPUT: EQN2

DESCRIPTION:

- equation is as follows,

$$EQN2 = \sqrt{\frac{\Gamma(k_2)}{\Gamma(k_1)^2} - 1} - COV$$

$$\text{where } k_2 = 1 + \frac{2}{x}$$

$$k_1 = 1 + \frac{1}{x}$$

- routine calls GAM to evaluate the gamma function ( $\Gamma$ )
- COV is the covariance of wind and x is the downwind distance from the source.

# SUBROUTINE ABSTRACT

NAME OF SUBROUTINE: FSIMP

FUNCTION OF SUBROUTINE: - calculate simple integration based on Simpson's Rule

INPUT: FUNC (100), M, RANGE

OUTPUT: - RES

DESCRIPTION:

- Monserco library routine

## SUBROUTINE ABSTRACT

NAME OF SUBROUTINE: FLARE

FUNCTION OF SUBROUTINE: - modifies the effective release height of the source due to the buoyancy of a flare.

INPUT: CFLARE, QRATE, AMTEMP, DTHDZ, STABILITY CLASS, USPEED, Z0, U10, ISOURCE

OUTPUT: USPEED, HEIGHT

DESCRIPTION:

- For unstable or neutral conditions,

$$\Delta h = 1.6 \frac{F^{1/3}}{U} (3.5x^*)^{2/3}$$

where F = CFLARE*QRATE

$x^* = 14 F^{5/8}$; $F \leq 55.$

$x^* = 34F^{2/5}$; $F > 55.$

if USPEED <0.5 → U=0.5

- stability category E,

$\Delta h$ is lesser of above and,

$$\Delta h = 2.6 \left(\frac{F}{US}\right)^{1/3}$$

if $U \leq 0.5$ $\Delta h = 5.3\, F^{\frac{1}{4}}\, S^{-3/8}$

$$S = \frac{g}{T} \left( \frac{d\theta}{dz} \right)$$

- stability category F,

$$\Delta h = 2.6 \left(\frac{F}{US}\right)^{1/3}$$

if $U \leq 0.5$ $\Delta h = 5.3F^{\frac{1}{4}}\, S^{-3/8}$

## SUBROUTINE ABSTRACT

NAME OF SUBROUTINE: GAM (G)

FUNCTION OF SUBROUTINE: - evaluation of the Gamma function ($\Gamma$)

INPUT: G

OUTPUT: ·GAM

DESCRIPTION:

- Monserco library subroutine
- a polynominal fit is used, error is $\leq 10^{-5}$
- re-occurrance relations are implemented for out-of-bounds case

# SUBROUTINE ABSTRACT

NAME OF SUBROUTINE: HEAVY

FUNCTION OF SUBROUTINE: - calculation of the preliminary dispersion of a heavier than air release to the point where it assumes a passive character.

INPUT: ALL INPUT is through subroutine READIN

OUTPUT: TRANSFER (5)

DESCRIPTION:

- calculates initial behaviour of gas if heavier than air
- modified from parts of 'DENZ'* such that if the heavy gas option is selected, the DENZ algorithms are executed up to the first step of stage 4 dispersion at which time the array TRANSFER returns processing to the normal passive release routines PUFF or LAKE.
- HEAVY calls subroutines READIN, TRANS, HSTAG2, STAGE2, STAGE3, STAGE4, which are described in DENZ documentation
- Output array TRANSFER(5) contains the required input to a passive puff:

TRANSFER(1) = position of cloud
TRANSFER(2) = height of cloud
TRANSFER(3) = radius of cloud
TRANSFER(4) = avg. concentration within cloud
TRANSFER(5) = mass of release

---

*DENZ - A computer program for the calculation of the dispersion of dense toxic or explosive gases in the atmosphere by L. S. Fryer and G. D. Kaiser, UKAEA Report SRD R152, July 1979

# SUBROUTINE ABSTRACT

NAME OF SUBROUTINE: INDOOR

FUNCTION OF SUBROUTINE: - calculates Indoor/Outdoor attenuation effect for Puff models.

INPUT: TAU, TAUB, CONC

OUTPUT: CONC

DESCRIPTION:

- the routine is called by PUFF if desired
- the concentration is modified by the factor x,

$$\text{where } x = \frac{1}{\left(\frac{\tau_B}{\tau} - 1\right)} \quad e^{\frac{-t'}{\tau_B}} - e^{\frac{-t'}{\tau}}$$

and $t'$ is evaluated at the peak,

$$t'_{MAX} = \frac{\ln \quad \left(\frac{\tau_B}{\tau}\right)}{\left(\frac{1}{\tau} - \frac{1}{\tau_B}\right)}$$

# SUBROUTINE ABSTRACT

NAME OF SUBROUTINE: INPUTC

FUNCTION OF SUBROUTINE: - to input all data specific to the dispersion cases

INPUT: DATA FILE 'GASPROB.DAT'

OUTPUT: ICASE, PROBJ (ICASE)

DESCRIPTION:

- routine initializes roughness values, stability parameters, and assigns coefficients used in dispersion calculations.

# SUBROUTINE ABSTRACT

NAME OF SUBROUTINE: INPUTP

FUNCTION OF SUBROUTINE: - input of probabilistic data

INPUT: DATA FILE 'PROBCON.DAT'

OUTPUT: See description of 'PROBCON.DAT'

DESCRIPTION:

- input of lethal threshold concentration curves to be stored in common block LINKUP

## SUBROUTINE ABSTRACT

NAME OF SUBROUTINE: INPUTR

FUNCTION OF SUBROUTINE: input dispersion data which is common to all dispersion cases

INPUT: DATAFILE 'GASPROB.DAT'

OUTPUT: see description of 'GASPROB.DAT'

DESCRIPTION:

- storage of run specific variables in common blocks PUFF, ATMOS, and RELTYPE including all processing options

## SUBROUTINE ABSTRACT

NAME OF SUBROUTINE: INPUTT

FUNCTION OF SUBROUTINE: - inputs required terrain from permanent data file 'TERRAIN.DAT'

INPUT: DATA FILE 'TERRAIN.DAT'

OUTPUT: CGX, CGY, POP, ELEV

DESCRIPTION:

- routine reads all data required to establish a site specific model of the local terrain, including elevations and population.
- calls routine DIVIS to subdivide model for additional terrain definition if required.
- establishes grid point locations for use by CONVERT

## SUBROUTINE ABSTRACT

NAME OF SUBROUTINE: INTEGRAL

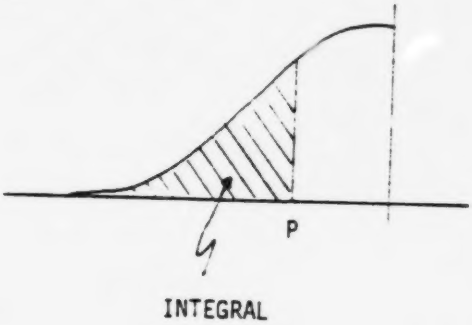
FUNCTION OF SUBROUTINE: - integrates a Gaussian distribution to a specified value of P

INPUT: P

OUTPUT: INTEGRAL

DESCRIPTION:

- routine calls FSIMP to perform a Simpson's Rule integration
- the array FUNC(100) is established with the range of values for $e^{-50}$ to $e^{-P/2}$



$$\text{INTEGRAL} = \frac{1}{\sqrt{2\pi}} \int_{-\infty}^{P} e^{\frac{-p^2}{2}} \, dp$$

$$P = \frac{L(x_1) - H}{\sigma_z (x)}$$

## SUBROUTINE ABSTRACT

NAME OF SUBROUTINE: LAKE

FUNCTION OF SUBROUTINE: - calculates dispersion based on Lyons' 3-stage model representing a lakebreeze effect.

INPUT: XCORD, YCORD, SIG, XBE, USPEED, QRATE, H
PUFFT, PUFFQ, BOUNDL, INTEGRAL, TRAP

OUTPUT: CONC

DESCRIPTION:

See reference*

---

* Turbulent Diffusion and Pollutent Transport in Shoreline Environments by W. A. Lyons.
In Lectures on Air Pollution and Environmental Impact Analyses, AMS, Boston, Mass., 1975

# SUBROUTINE ABSTRACT

NAME OF SUBROUTINE: LINK

FUNCTION OF SUBROUTINE: - functions as a liaison to the modified $H_2$SRISK routine RISK

INPUT: - all Probability Consequence data, CONC, POP

OUTPUT: PK, FIXJ, GRIDFAT

DESCRIPTION:

- for each grid point, routine RISK is called to determine the probability of short term concentrations exceeding the k% lethal concentration for exposure time $(x_t)$.
- the sum of the probabilities among the different exposure times is selected as representative of the probability that K% of the population will be affected (PK(k)).
- the PK (k) array is used to interpolate at set values of probability PJ to establish percentage of affected population (within that terrain location), FIXJ (J).
- the interpolation is a simple linear interpolation. For values of PJ outside range of PKs, interpolation to the known limits of (0.,1.) and (1.,0.) are used.
- the affected population is summed over entire terrain map and stored for each case as GRIDFAT (ICASE,J) where J is the index corresponding to the specified PJ.

# SUBROUTINE ABSTRACT

NAME OF SUBROUTINE: MAIN

FUNCTION OF SUBROUTINE: - mainline of code which directs processing to applicable subroutines.

INPUT: N/A

OUTPUT: N/A

DESCRIPTION:

- opens all required files for Input/Output
- calls required routines:

  INPUTT, INPUTR, OUTPUT*, TERRPLOT*, INPUTP*,
  INPUTC, CONVERT, VJET*, FLARE*, HEAVY*, TERR,
  LAKE*, PLUME*, PUFF*, DOCOUT, ACCUMMU,
  LINK, SUMMAT, PROBOUT

  where * is called optionally

- writes status report to terminal of user.
- calculates the wind speed at the physical release height from the input 10. metre reference height for input to VJET or FLARE.
- if HEAVY is called, array TRANSFER is processed to make it compatible with PUFF for passive dispersion phase of release.

## SUBROUTINE ABSTRACT

NAME OF SUBROUTINE: OUTPUT

FUNCTION OF SUBROUTINE: - provide a terrain listing of converted data

INPUT: terrain data

OUTPUT: File listing

DESCRIPTION:

- this listing is created if activated.

## SUBROUTINE ABSTRACT

NAME OF SUBROUTINE: PLOT2

FUNCTION OF SUBROUTINE: - called by TERRPLOT to condition plot variables

INPUT: terrain data X, Y, NELM, XNEW, YNEW, NEWNODE

OUTPUT: Calcomp compatible file suitable for plotting

DESCRIPTION:

- Monserco library routine
- produces a high definition plot of the original terrain data or the internally subdivided data.

# SUBROUTINE ABSTRACT

NAME OF SUBROUTINE: PLUME

FUNCTION OF SUBROUTINE: - determine the concentration of gas at each grid location based on a passive plume model assumption

INPUT: SIG, TRAP

OUTPUT: CONC

DESCRIPTION:

- model based on,

$$\text{CONC}\ (x,y) = \frac{Q\ (\text{ISOURCE})}{\pi\ \sigma y\ (x)\ \sigma_z(x)\ u}\ e^{-\frac{1}{2}\left(\frac{y}{\sigma y(x)}\right)^2} * \text{TRAP}$$

- where TRAP returns the term of the dispersion relation which contains the influence of height of release and trapping.

## SUBROUTINE ABSTRACT

**NAME OF SUBROUTINE:** PROBOUT

**FUNCTION OF SUBROUTINE:** - provide listing of overall consequence of release

**INPUT:** $\nu$, PROB ($\nu$)

**OUTPUT:** File listing

**DESCRIPTION:**

N/A

## SUBROUTINE ABSTRACT

NAME OF SUBROUTINE: PUFF

FUNCTION OF SUBROUTINE: - calculate concentrations at each grid point assuming a number of discreet puffs.

INPUT: SIG, PUFFT, PUFFQ

OUTPUT: CONC

DESCRIPTION:

- formula used for puff (i),

$$c\,(x,y,t,i) = \frac{2\,Q\,(\mathrm{ISOURCE},\,i)}{(2\pi)^{3/2}\sigma_y^{2}\,\sigma_z}\, e^{-\frac{1}{2}\left(\frac{y}{\sigma_y}\right)^2}\, e^{-\frac{1}{2}\left(\frac{x-ut}{\sigma_y}\right)} * \mathrm{TRAP}$$

- where TRAP is the height influence which may include trapping effects
- the method of searching for the peak concentration was as follows:

time at which each puff arrives at grid point $x = t_0 + \frac{x}{u}$
where $t_0$ is the time of release, x is the distance, u is wind speed.
the limit of 'influence' of each puff was assumed to be where the concentration had dropped to less than 1 % of its peak value, it can be shown that the region of influence of puff (i) is $\pm\ 3.035\,\frac{\sigma y}{u}$ .
IF INDOOR/OUTDOOR attenuation effect is required INDOOR is called.

## SUBROUTINE ABSTRACT

NAME OF SUBROUTINE: RISK

FUNCTION OF SUBROUTINE: - modification of $H_2S$ RISK used to calculate the probability of exceeding the concentration $x_t$

INPUT: V, FMAX, C, A, ZO, T, S, B, XT, FO, D, XS

OUTPUT: PROBAB

DESCRIPTION:

- see description of $H_2S$ RISK *

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* The Influence of Short-term Concentration Peaks on Exposure Risks in the Vicinity of an Episodic Release of Hydrogen Sulphide, a research report prepared for the Atomic Energy Control Board by Monserco Limited, May 1981.

# SUBROUTINE ABSTRACT

**NAME OF SUBROUTINE:** ROOT

**FUNCTION OF SUBROUTINE:** - Newton-Raphson iteration for finding root of EQN2

**INPUT:** COV

**OUTPUT:** ROOT

**DESCRIPTION:**

- Monserco library routine
- called by RISK

# SUBROUTINE ABSTRACT

NAME OF SUBROUTINE: SIG

FUNCTION OF SUBROUTINE: - establishes values of the dispersion coefficients $\sigma_y$ (x) and $\sigma_z$ (x)

INPUT: SIG1, SIG2, SIG3,SIGADJ

OUTPUT: $\sigma_y$, $\sigma_z$

DESCRIPTION:

- routes processing to one of 4 calculation options listed above

## SUBROUTINE ABSTRACT

NAME OF SUBROUTINE: SIG1

FUNCTION OF SUBROUTINE: - performs calculations for default dispersion coefficient calculation

INPUT: $x$, $\sigma_\phi$, $\sigma_\theta$

OUTPUT: $\sigma_y$, $\sigma_z$

DESCRIPTION:

$$\sigma_y = \sigma_\theta \; x \; F(x)$$

$$\sigma_z = \sigma_\phi x$$

where F (x) is interpolated from the following table,

| x<br>(m) | F (x) |
|---|---|
| <100. | 0.8 |
| 100. | 0.8 |
| 200. | 0.7 |
| 400. | 0.65 |
| 1000. | 0.60 |
| 2000. | 0.50 |
| 5000. | 0.40 |
| 10000. | 0.33 |
| >10000. | $0.33 \left(\frac{10}{x}\right)^{\frac{1}{2}}$ |

## SUBROUTINE ABSTRACT

NAME OF SUBROUTINE: SIG2

FUNCTION OF SUBROUTINE: Briggs model of dispersion coefficients

INPUT: x, STABILITY

OUTPUT: $\sigma_y$, $\sigma_z$

DESCRIPTION:

- calculation is performed according to the following table,

| STABILITY | $\sigma_y$ | $\sigma_z$ |
|---|---|---|
| A | 0.22 K | 0.20 x |
| B | 0.16 K | 0.12 x |
| C | 0.11 K | $0.08x\ (1 + 0.0002x)^{-\frac{1}{2}}$ |
| D | 0.08 K | $0.06x\ (1 + 0.0015x)^{-\frac{1}{2}}$ |
| E | 0.06 K | $0.03x\ (1 + 0.0003x)^{-1}$ |
| F | 0.04 K | $0.016x\ (1 + 0.0003x)^{-1}$ |

where $K = x(1+0.0001x)^{-\frac{1}{2}}$

## SUBROUTINE ABSTRACT

NAME OF SUBROUTINE: SIG3

FUNCTION OF SUBROUTINE: - calculation of dispersion coefficients following Smith-Hosker.*

INPUT: x, STABILITY, ROUGHNESS

OUTPUT: $\sigma_y$, $\sigma_z$

DESCRIPTION: The applicable equations are as Follows;

$$\sigma_z = g(x)\, F(z_0, x)$$

$$\sigma_y = c_3 x / (1 + 0.0001 x)^{\frac{1}{2}}$$

where $g(x) = a_1 x^{b_1} / (1 + a_2 x^{b_2})$

and, $F(z_0,x) = \ln c_1 x^{d_1} (1 + 1/c_2 x^{d_2})$ if $z_0 >$ 10cm

or, $F(z_0,x) = \ln c_1 x^{d_1} / (1 + c_2 x^{d_2})$ if $z_0 \leq$ 10cm

The parameters a, b, and c depend on atmospheric stability or terrain roughness length as shown in the following tables;

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*Estimates of Dry Depostion and Plume Depletion over Forests and Grassland by R.P. Hosker. IAEA Paper SM-181/19, 1974.

| Example of Surfaces | Roughness length $z_0$ | $c_1$ | $d_1$ | $c_2$ | $d_2$ |
|---|---|---|---|---|---|
| Lawn grass | 1 cm | 1.56 | 0.048 | $6.25 \times 10^{-4}$ | 0.45 |
| Plowed land | 4 cm | 2.02 | 0.027 | $7.76 \times 10^{-4}$ | 0.37 |
| Open grass-land | 10 cm | e | 0 | 0 | 0 |
| Tall bushes | 40 cm | 5.16 | -0.098 | 18.6 | -0.225 |
| Forested area or cities | 100 cm | 7.37 | -0.0957 | $4.29 \times 10^{3}$ | -0.60 |
| Cities with tall bldgs. | 400 cm | 11.7 | -0.128 | $4.59 \times 10^{4}$ | -0.78 |

| Pasquill Stability Category | $a_1$ | $b_1$ | $a_2$ | $b_2$ | $c_3$ |
|---|---|---|---|---|---|
| A | 0.112 | 1.060 | $5.38 \times 10^{-4}$ | 0.815 | 0.22 |
| B | 0.130 | 0.950 | $6.52 \times 10^{-4}$ | 0.750 | 0.16 |
| C | 0.112 | 0.920 | $9.05 \times 10^{-4}$ | 0.718 | 0.11 |
| D | 0.098 | 0.889 | $1.35 \times 10^{-3}$ | 0.688 | 0.08 |
| E | 0.0609 | 0.895 | $1.96 \times 10^{-3}$ | 0.684 | 0.06 |
| F | 0.0638 | 0.783 | $1.36 \times 10^{-3}$ | 0.672 | 0.04 |

## SUBROUTINE ABSTRACT

NAME OF SUBROUTINE: SIGADJ

FUNCTION OF SUBROUTINE: - performs an adjustment to the dispersion coefficients for gravity effects or building effects.

INPUT: $\sigma_y$, $\sigma_z$, RT, XT, HT, C, A0

OUTPUT: $\sigma_y$, $\sigma_z$

DESCRIPTION:

gravity effect:

$$\sigma_y^2 (x) = \left(\frac{\overline{t}}{2.14}\right)^2 + \sigma_y^2 \; (x-x_t) \qquad \text{(option 1)}$$

$$\sigma_z^2 (x) = \left(\frac{h_t}{2.14}\right)^2 + \sigma_y^2 \; (x-x_t)$$

building effect:

$$\sigma_y^2 (x) = \sigma_y^2 (x) + \frac{CAo}{-} \qquad \text{(option 2)}$$

$$\sigma_z^2 (x) = \sigma_z^2 (x) + \frac{CAo}{-}$$

## SUBROUTINE ABSTRACT

NAME OF SUBROUTINE: SUMMAT

FUNCTION OF SUBROUTINE: - sums probabilities corresponding to number of affected people, $\nu$ for each dispersion case.

INPUT: PROBJ (ICASE), $\nu$, GRIDFAT (ICASE, $\nu$)

OUTPUT: PROB ($\nu$)

DESCRIPTION:

N/A

## SUBROUTINE ABSTRACT

NAME OF SUBROUTINE: TERR

FUNCTION OF SUBROUTINE: - modifies effective release height by terrain elevation differences

INPUT: HEIGHT, ELEV, ELEVSOUR

OUTPUT: H

DESCRIPTION:

- if no terrain modification required, H (I) = HEIGHT (ISOURCE)
- modification is

  H(I) = HEIGHT(ISOURCE)-(ELEV(I)-ELEVSOUR(ISOURCE))

- if H(I) <10. H(I) = 10. and a warning is issued

## SUBROUTINE ABSTRACT

NAME OF SUBROUTINE: TERRPLOT

FUNCTION OF SUBROUTINE: - plot terrain definition file compatible with Monserco plotter

INPUT: terrain data

OUTPUT: plot file 'PLTDAT.VEC'

DESCRIPTION:

- Monserco library routine
- groups of the terrain map can be isolated for large plots

## SUBROUTINE ABSTRACT

NAME OF SUBROUTINE: TRAP

FUNCTION OF SUBROUTINE: - calculates the height dependent term for all passive dispersion routines, trapping effect may be included.

INPUT: XLID, SIG, H

OUTPUT: TRAP

DESCRIPTION:

- trapping effect = K

$$K = \sum_{N=1}^{4} \left[ e^{-\frac{1}{2}\left(\frac{H + 2NL}{\sigma_z}\right)^2} + e^{-\frac{1}{2}\left(\frac{H - 2NL}{\sigma_z}\right)^2} \right]$$

if trapping is not required K = 0

$$TRAP = K + e^{-\frac{1}{2}\left(\frac{H}{\sigma_z}\right)^2}$$

## SUBROUTINE ABSTRACT

**NAME OF SUBROUTINE:** VJET

**FUNCTION OF SUBROUTINE:** - calculation of effective release height for a vertical jet.

**INPUT:** USPEED, U10, W0, DISCH, X, Z0, HEIGHT, DTHDZ, AMTEMP

**OUTPUT:** HEIGHT, USPEED

**DESCRIPTION:**

- change of effective release height, $\Delta h$ is calculated as follows,

Stability A,B,C,D:

$$\Delta h = 3D \left(\frac{W0}{U} - 1\right)$$

where D = break diameter

W0 = initial jet velocity

U = wind speed (if U ≤0.5 - U = 0.5)

Stability E,F:

$$\Delta h = 1.5 \left(\frac{M}{U}\right)^{1/3} S^{-1/6}$$

where $M = \frac{W0^2 \quad D^2}{4}$

if $U \leq 0.5$,

$$\Delta h = 2.44 \left(\frac{M}{S}\right)^{\frac{1}{4}}$$

$$S = \frac{g}{T}\left(\frac{d\theta}{dz}\right)$$

## SUBROUTINE ABSTRACT

NAME OF SUBROUTINE: XBE

FUNCTION OF SUBROUTINE: - calculates the limits $X_B$ and $X_E$ for subroutine LAKE

INPUT: grid point I

OUTPUT: $X_B$ or $X_E$

DESCRIPTION:

- uses a Newton-Raphson iteration to converge
- calls EQN for values of expression
- 25 iterations max

## SUBROUTINE ABSTRACT

NAME OF SUBROUTINE: XØFUNC

FUNCTION OF SUBROUTINE: - return position of virtual source for use with LAKE

INPUT: XEOUT, ILAKE, H, SIG

OUTPUT: XØFUNC

DESCRIPTION:

- calculates the position of the virtual source by the following formula,

$$\text{XØFUNC} = x' = x_e - \frac{x_e \ \sigma_{yF}(x_e)}{\sigma_y \ (u, x_e)}$$

where $\sigma_{yF} = \sigma_y + \frac{H}{8}$

# APPENDIX C

C.0 SUMMARY OF INPUT DATA

C.1 PROBCON.DAT

C.2 TERRAIN.DAT

C.3 GASPROB.LIS

# C.0 SUMMARY OF INPUT DATA

## C.0 SUMMARY OF INPUT DATA

### 1. TERRAIN.DAT

Record 1. IPOP

- IPOP is population data input type
  .NE.1 variable POPDENS is population
  .EQ.1 variable POPDENS is population density

Record 2. K, (NELM (I,J), J=1,4), IDIV (I), POPDENS (I), ELEVOLD (I)

- 1 record required for specification of each terrain element, maximum of 1000.

- K = terrain element number

- (NELM (I,J), J=1,4) the four coordinate numbers specifying the Ith element (must be specified in a clockwise direction)

- IDIV (I) number of subdivisions element should be divided in each direction for internal processing. (i.e. IDIV(I) = 3 will produce 9 grid points for increased terrain definition)

- POPDENS (I) population or population density within terrain element I.

- ELEVOLD (I) elevation of element I

NOTE: a blank record ends element definition.

Record 3. K, X(K), Y(K)

- K is the coordinate number
- X(K) is the X coordinate of K in km
- Y(K) is the Y coordinate of K in km

## 2. GASPROB.DAT

Record 1. IRUNCODE, TITLE

- IRUNCODE = 1 Normal run
= 2 Dispersion calculations only

-TITLE is the title of run (≤80 char.)

Record 2. (IOPTION (I), I = 1,11)

-IOPTION (1) Plume Model=1, Puff Model.NE.1
Indoor/outdoor peak to mean effect
of puff model = 3
-IOPTION (2) Sigma y,z options 1,2, or 3
-IOPTION (3) Weather class (1=A, 2=B,...6=F)
-IOPTION (4) Terrain Roughness (1,2,...6)
-IOPTION (5) Gravity effect option (1=include)
-IOPTION (6) Building effect option (1=include)
-IOPTION (7) Terrain modification (1=include)
-IOPTION (8) Trapping option (1=include)
-IOPTION (9) Lake breeze effect (1=include)
-IOPTION (10) Debug Diagnostic Switch
= 1 Additional listing included
= 2 Terrain plot included
-IOPTION (11) Type of Release
= 1 Passive Release
= 2 Vertical Jet
= 3 Flare
= 4 Heavier than air

Record 3. XLID, WIND, USPEED, SIGTHETA, SIGPHI

-XLID = lid height (metre)
-WIND = wind direction (direction relative to +y axis from which wind is blowing (in degrees))
-USPEED = reference wind speed at 10 meters (m/sec)
-SIGTHETA = dispersion constant σTHETA
-SIGPHI = dispersion constant σPHI

Record 4. -C,A0 = building effect constants
-IWCLASS2 = stability class inside thermal internal boundary layer (TIBL)

Record 5. I, SX(I), SY(I), ELEVSOUR(I), HEIGHT(I), QRATE(I), XLS(I), DISCH(I), SO2FLOW(I)

- Source Data
- I = source number
- SX, SY = source co-ordinates
- ELEVSOUR = elevation of ground at source
- HEIGHT = source height above ELEVSOUR
- QRATE = plume release rate (optional)
- XLS = distance from lakeshore to source measured along wind axis (optional)
- DISCH = effective discharge diameter (optional)
- SO2FLOW = flow of SO2 from break (optional)

A blank record ends the source data input

Record 6. IPUFF
- IPUFF is the source number for puff data

Record 7. - PUFFT (IPUFF, I), PUFFQ (IPUFF,I) (optional)
- PUFFT = time of release of I-th puff for source IPUFF
- PUFFQ = size of release

A blank record ends puff input data for source IPUFF. Up to 100 sets of records 6 and 7 can be input to specify multiple sources, input ceases on IPUFF = 0

Record 8. TAU, TAUB

-TAU = $\tau$, the effective time constant of the blowdown

-TAUB = $\tau_B$, the effective time constant of the building

Record 9. ICASE, P

- ICASE is the present meteorological case under processing
- P is the probability of ICASE occurring

- maximum of 1000 cases considered per run
- some data presently read in INPUTR (records 1-5) will be read by INPUTC such that the values of those parameters may be altered from case to case
- ICASE = 0 signifies all cases have been processed

## 3. PROBCON.DAT

Record 1. Beta, C, A, FMAX, S

-Beta, C,A,FMAX = atmospheric constants

-S = episode duration (sec)

Record 2. PERC(I)

-PERC(I) = percentile corresponding to the Ith lethal dose function

Record 3. TCLT(I,J), CLT(I,J)

-TCL(I,J) = exposure time of the J'th point on the I'th percentile lethal dose curve (sec)

-CLT(I,J) = lethal dose corresponding to TCL (I,J) (units of release)

Note: - there can be up to 10 record 3's specifying the I'th lethal dose curve (if less than 10) end data with blank line)

- there can be up to 10 sets of records 2 and 3 specifying the different percentile lethal concentration curves (if less tnan 10 sets, end with a blank record)

Record 4. PJ (J), J = 1,10

- PJ (J), J = 1,10 = up to 10 fixed values of probability which are used to sum the accumulated affected population

Record 5. NU(J), J = 1,10

- NU(J), J = 1,10 = up to 10 specified number of people affected to be considered in final probability calculation.

## C.1 DATA FILE

PROBCON.DAT

```
4 ,2 8,1 ,0 20,1000 ,
0 01,
6 ,1200 ,
30 ,700 ,
600 ,400 ,

0 50,
6 ,2000 ,
30 ,2400 ,
600 ,1400 ,


1 E-7,1 E-5,1 E-3,1 E-1,
1 ,2 ,5 ,10 ,50 ,100 ,500 ,
```

## C.2 DATA FILE

TERRAIN.DAT

```
 0.
 1.  22.  23.  20. 526.   0.   93.00000000   , 0.0000000000E+00,
 2.  23.  24.  17.  19.   0. 3615.000000     ,  15.24390221     ,
 3.  20.  19.  18.  21.   0. 3615.000000     ,  30.48780441     ,
 4.   1.   4.   3.   2.   0.   56.00000000   ,  60.97560083     ,
 5.   4.   6.   5.   3.   0.  140.0000000    ,  60.97560083     ,
 6.  19.  16.  15.   4.   0.  270.0000000    ,  53.35366058     ,
 7.   6.   9.   7.   8.   0.   55.00000000   ,  68.59756470     ,
 8.   9.  15.  10.   7.   0.   55.00000000   ,  76.21951294     ,
 9.  12.  14.  13.  10.   0.   55.00000000   ,  76.21951294     ,
10.  25.  26.  14.  12.   0.  269.0000000    ,  45.73170853     ,
11. 527.  27.  13.  26.   0.  227.0000000    ,  30.48780441     ,
12.  27.  40.  39.  28.   0.  247.0000000    ,  15.24390221     ,
13.  28.  39.  37.  29.   0.  228.0000000    ,  45.73170853     ,
14.  29.  37.  35.  11.   0.  194.0000000    ,  83.84146118     ,
15.  11.  35.  34.  10.   0.   28.00000000   , 106.7073212      ,
16.  10.  33.  31.  30.   0.  328.0000000    , 129.5731659      ,
17.  40.  52.  51.  39.   0.   19.00000000   ,  15.24390221     ,
18.  39.  50.  49.  38.   0.   71.00000000   ,  38.10975647     ,
19.  38.  49.  47.  37.   0.  228.0000000    ,  76.21951294     ,
20.  37.  46.  67.  36.   0.  290.0000000    ,  99.08536530     ,
21.  36.  67.  44.  34.   0.  336.0000000    , 114.3292694      ,
22.  33.  43.  42.  32.   0.   58.00000000   , 129.5731659      ,
23.  32.  57.  56.  31.   0.  337.0000000    , 137.1951294      ,
24.  52.  66.  65.  51.   0.   10.00000000   ,  15.24390221     ,
25.  50.  63.  61.  48.   0.  282.0000000    ,  53.35366058     ,
26.  48.  61.  60.  47.   0.  141.0000000    ,  91.46341705     ,
27.  46.  60.  59.  45.   0.   70.00000000   , 106.7073212      ,
28.  45.  59.  58.  44.   0.   56.00000000   , 114.3292694      ,
29.  43.  58.  57.  42.   0.  101.0000000    , 129.5731659      ,
30.  41.  55.  54.  53.   0.  525.0000000    , 167.6829224      ,
31.  66.  89.  88.  64.   0.   97.00000000   ,  15.24390221     ,
32.  63.  88.  86.  62.   0.  290.0000000    ,  60.97560883     ,
33.  62.  86.  80.  60.   0.  212.0000000    , 106.7073212      ,
34.  60.  80.  78.  58.   0.  397.0000000    , 114.3292694      ,
35.  58.  78.  73.  56.   0.  303.0000000    , 137.1951294      ,
36.  55.  73.  71.  54.   0.  519.0000000    , 167.6829224      ,
37.  82.  84.  83.  81.   0. 1088.000000     , 121.9512177      ,
38.  74.  76.  75.  72.   0. 2097.000000     , 129.5731659      ,
39.  90. 114. 112.  87.   0.  909.0000000    ,  45.73170853     ,
40.  87. 111. 106.  85.   0.  355.0000000    ,  68.59756470     ,
41.  85. 106. 102.  79.   0.  438.0000000    ,  91.46341705     ,
42.  79. 102. 101.  78.   0.  250.0000000    , 121.9512177      ,
43.  78. 101.  99.  77.   0.  134.0000000    , 121.9512177      ,
44.  77.  99.  98.  74.   0.  410.0000000    , 121.9512177      ,
45.  76.  98.  97.  75.   0.  136.0000000    , 121.9512177      ,
46.  72.  75.  96.  70.   0.  400.0000000    , 152.4390259      ,
47.  70.  94.  93.  69.   0.   42.00000000   , 152.4390259      ,
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 68.   56 25000000   .   16 25000000   .
 69.   52 25000000   .   18 25000000   .
 70.   51 00000000   .   19 00000000   .
 71.   49 00000000   .   20 00000000   .
 72.   38 75000000   .   25 25000000   .
 73.   38 00000000   .   25 50000000   .
 74.   37 50000000   .   26 00000000   .
 75.   39 75000000   .   26 75000000   .
 76.   38 50000000   .   27 50000000   .
 77.   32 75000000   .   28 50000000   .
 78.   29 75000000   .   30 00000000   .
 79.   25 00000000   .   32 25000000   .
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 83.   22 50000000   .   35 00000000   .
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 86.   16 75000000   .   36 75000000   .
 87.   8 750000000   .   40 75000000   .
 88.   5 750000000   .   42 50000000   .
 89.   3 250000000   .   43 75000000   .
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 91.   57 25000000   .   17 75000000   .
 92.   56 50000000   .   18 50000000   .
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 94.   51 75000000   .   20 75000000   .
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 96.   46 50000000   .   27 50000000   .
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 99.   33 75000000   .   30 75000000   .
100.   37 00000000   .   34 25000000   .
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102.   20 75000000   .   37 50000000   .
103.   23 50000000   .   42 50000000   .
104.   24 25000000   .   44 25000000   .
105.   22 50000000   .   45 25000000   .
106.   21 50000000   .   43 25000000   .
107.   16 25000000   .   45 50000000   .
108.   17 00000000   .   47 00000000   .
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238.   69 00000000   .   62 29999924   .
239.   67 00000000   .   62 25000000   .
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243.   61 75000000   .   57 29999924   .
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265.   19 39999962   .   68 19999695   .
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527.   5 900000095   ,   17 89999962   ,
528.   10 14999962   ,   62 75000000   ,
529.   20 00000000   ,   61 90000153   ,
530.   62 95000076   ,   94 94999695   ,
531.   49 65000153   ,   110 6999969   ,
532.   48 04999847   ,   120 8000031   ,
533.   45 54999924   ,   122 5999985   ,
534.   64 90000153   ,   97 19999695   ,
535.   65 59999847   ,   99 30000305   ,
536.   65.44999695    ,  100.0000000    ,
537.   41.54999924    ,  108.9000015    ,
538.   40.79999924    ,  111.5000000    ,
539.   40.25000000    ,  114.2500000    ,
540.   40.29999924    ,  111.1999969    ,
541.   54.15000153    ,   55.59999847   ,
  0.  0.0000000000E+00,  0.0000000000E+00,
```

## C.3 SAMPLE OUTPUT

GASPROB.LIS

```
                    P R O G R A M   G A S P R O B
                    - - - - - - -   - - - - - - -

RUN TITLE . TEST RUN OF DISPERSION SEGMENT OF GASPROB, MAY 24,1983


    RUN SPECIFICATIONS :

REFERENCE WIND SPEED (10  METRE) :                  5.0000      M/SEC
WIND DIRECTION (FROM) :                  270.00      DEGREES

LID HEIGHT (OPTIONAL) :                1000.0      METRES
STABILITY WITHIN THE TIBL (OPTIONAL) :  1
TIME CONSTANT OF BLOWDOWN :    1.0000
TIME CONSTANT OF BUILDINGS :    2.0000
ATMOSPHERIC PARAMETERS SIGTHETA,SIGPHI,XT,RT,HT,C,AO :
     10.00        10.00        1.000        1.000        1.000        1.000        1.000

METHOD OF CALCULATION OPTIONS :  1 3 4 3 0 0 0 0 0 1 1

PLUME SOURCE DATA

ELEVATION      HEIGHT        X             Y            RATE OF      DISTANCE      DISCHARGE       SO2
AT SOURCE     OF SOURCE    COORD          COORD         RELEASE      FROM LAKE      DIAMETER     FLOW RATE

0.00000E+00  0.00000E+00  14500.        73000.       0.33500E+09  0.00000E+00  0.00000E+00  0.00000E+00
```

```
--- DEBUGGING DUMP OF TERRAIN DATA ---
 I,CGX,CGY,AREA,POP :


    1      6375.0000      8225.0000      687499.94      93.000000
    2      6875.0000      9125.0000      3187500.0      3615.0000
    3      7625.0000      7875.0000      1937500.0      3615.0000
    4      15687.500      3125.0000      8500000.0      56.000000
    5      15812.500      7062.5000      26281250.      140.00000
    6      11437.500      10250.000      22718750.      270.00000
    7      15750.000      10375.000      7687500.0      55.000000
    8      16437.500      12062.500      12375000.      55.000000
    9      16875.000      14125.000      6750000.0      55.000000
   10      10375.000      14062.500      20812500.      269.00000
   11      8162.5000      17287.500      31050000.      227.00000
   12      5812.5000      22812.500      4593750.0      247.00000
   13      9875.0000      20437.500      25812500.      228.00000
   14      16625.000      16562.500      19656250.      194.00000
   15      20687.500      14437.500      5062500.0      28.000000
   16      26312.500      12937.500      51656250.      328.00000
   17      5562.5000      28187.500      7406250.0      19.000000
   18      7625.0000      26500.000      13875000.      71.000000
   19      12125.000      23875.000      36562500.      228.00000
   20      17512.500      22312.500      29918752.      290.00000
   21      21625.000      20250.000      46875000.      336.00000
   22      25437.500      17937.500      7875000.0      58.000000
   23      30937.500      18687.500      52093750.      337.00000
   24      5375.0000      32437.500      2343750.0      10.000000
   25      10375.000      30750.000      50687500.      282.00000
   26      16187.500      27750.000      20625000.      141.00000
   27      20950.000      26750.000      15500002.      70.000000
   28      25000.000      24687.500      9750000.0      56.000000
   29      27312.500      21687.500      17625000.      101.00000
   30      39937.500      15562.500      53156250.      525.00000
   31      5000.0000      38250.000      19000000.      97.000000
   32      10687.500      36812.500      58218750.      290.00000
   33      17875.000      33062.500      30937500.      212.00000
   34      24437.500      29625.000      50718750.      397.00000
   35      32687.500      25500.000      47187500.      303.00000
   36      42187.500      20125.000      72187500.      519.00000
   37      21562.500      34437.500      2500000.0      1088.0000
   38      38625.000      26375.000      2625000.0      2897.0000
   39      6500.0000      45312.500      49843750.      909.00000
   40      15125.000      42062.500      81468750.      355.00000
   41      23250.000      37812.500      66187500.      438.00000
   42      28750.000      35337.500      34549999.      250.00000
   43      31937.500      32212.500      22668747.      134.00000
   44      35562.500      29250.000      19156250.      410.00000
   45      38962.500      29562.500      5687496.2      136.00000
   46      44000.000      24625.000      42687500.      400.00000
   47      52187.500      19812.500      4000000.0      42.000000
   48      54875.000      18375.000      11875000.      124.00000
   49      54500.000      22687.500      12656250.      124.00000
   50      52000.000      24000.000      12750000.      405.00000
   51      50125.000      23062.500      14593750.      133.00000
   52      48562.500      26937.500      4687500.0      25.000000
   53      55437.500      27000.000      12312500.      124.00000
   54      5562.5000      50375.000      2093750.0      22.000000
 55     6812 5000     52000.000     2000000 0     171 00000
 56     8625 0000     54125.000     3187500 0     666 00000
 57    10437 500      50875.000     44250000      320 00000
 58    16250 000      46375 000     1312500.0     591 00000
 59    10187 500      47937 500     53781250      288 00000
 60    22937 500      43812 500     4281250 0     27 000000
 61    27000 000      41462.500     12474997.     65 000000
 62    34312 500      37125.000     36000000      205 00000
 63    42062 500      37250 000     42968750      295 00000
 64    41012 500      34062 500     29500000      159 00000
 65    44400 000      30375.000     62287506      401.00000
 66    53375 000      31687.500     66281250.     508 00000
 67    61062 500      33500.000     61843750.     382 00000
 68    39812 500      38937.500     1968750.0     1026 0000
 69    54062 500      38312.500     53500000.     319.00000
 70    41062 500      41375 000     52031250.     327 00000
 71    11187 500      56412 500     6743750 6     4321 0000
 72    10937 500      57325.000     743750:09     1457 0000
 73    12250 000      58750.000     165000 31     3 0000000
 74    13000 000      60200.001     14750000.     1144.0000
 75    16187 500      56812.500     52125000      485.00000
 76    22312.500      53125.000     62924994.     415.00000
 77    28000.000      46437.500     60693762.     389.00000
 78    35187.500      44687.500     42250000.     204.00000
 79    37250.000      49125.000     43187500.     216 00000
 80    42500.000      46500.000     28500000.     452.00000
 81    50437.500      41750.000     29031250.     311.00000
 82    53312.500      44125.000     2406250.0     927.00000
 83    55312.500      42250.000     9906250.0     156.00000
 84    60250.000      40625.000     12937500.     80.000000
 85    68812.500      40937.500     41312500.     316.00000
 86    65875.000      43312.500     11343750.     79.000000
 87    71000 000      44375.000     8375000.0     39.000000
 88    71562.500      47125.000     21187500.     158.00000
 89    67500.000      46125.000     2375000.0     464 00000
 90    65312.500      46312.500     24937500      196.00000
 91    59937.500      43687.500     24937500.     252.00000
 92    62750.000      48125.000     3187500 0     511.00000
 93    59062.500      47875.000     23593750.     189.00000
 94    55312 500      46437.500     11468750.     126 00000
 95    52125 000      46312 500     16156250.     156.00000
 96    48062 500      45375 000     16343750      221 00000
 97    31375.000      53375.000     47362503.     265.00000
 98    36812.500      56700.001     25575009.     207.00000
 99    41375 000      57850.000     12850001.     116.00000
100    39312 500      53187.500     37218750      311.00000
101    49312 500      53050.000     50537504.     613 00000
102    45350 000      58875.000     40990013.     507 00000
103    50287 500      60062.500     40231250.     296.00000
104    50500.000      52875.000     5187500 0     4682.0000
105    57475.000      54224.999     23264990.     579 00000
106    55975 000      56550.000     5015002 1     123.00000
107    54687.500      58950.000     11762497      83 000000
108    57937.500      58987 500     14699996      370 00000
109    60600 000      56212 500     4600002 3     6316 0000
110    64537 500      55575 000     28934999      779 00000
111    63412 500      59700 000     41502508      427.00000
112    68275 000      61387.500     3652497.6     40 000000
113    72687 500      58062 500     44250000      588 00000
114    77125 000      59412 500     3843749.0     2458.0000
115    16162 500      65187.500     36212504.     510 00000
```

```
116    20000.000    64262.501    1012490.9    110.00000
117    10662.500    61462.500    4003753.9    41.000000
118    21287.500    62462.500    11720000     157.00000
119    25687.500    59687.500    56812495     302.00000
120    36037.500    60775.000    40252477     465.00000
121    46275.000    65950.000    53779907.    346.00000
122    53787.499    68825.001    18373747.    116.00000
123    54062.500    64287.500    35928771.    421.00000
124    58437.499    66600.000    19075000     380.00000
125    64424.999    63025.000    20575002.    213.00000
126    72299.999    63962.500    49226257     357.00000
127    77712.500    65900.000    24512491.    60.000000
128    64200.000    69087.502    71990023.    402.00000
129    71637.501    70000.001    31765020.    201.00000
130    77262.501    71850.000    41693743.    138.00000
131    18350.000    67662.500    2781249.2    806.00000
132    14800.000    73112.501    10443753.    25.000000
133    18925.000    71799.999    55442479     568.00000
134    27050.000    66462.500    77114973.    469.00000
135    25200.000    72049.999    7515005.5    39.000000
136    37550.000    68112.499    55638775.    295.00000
137    41562.500    69674.999    11068751.    49.000000
138    49400.000    71500.000    54599995     349.00000
139    54162.500    72275.000    2669999.4    1840.0000
140    60537.500    74787.500    54669992.    388.00000
141    60675.001    78275.002    69837468.    518.00000
142    76625.000    77862.501    44443747.    145.00000
143    81562.500    79450.001    26230000     79.000000
144    23962.500    77237.499    68308772.    352.00000
145    32175.000    71912.498    68741235.    320.00000
146    39812.500    72375.000    1351249.0    1039.0000
147    43099.999    74350.000    34420011.    160.00000
148    50025.001    75575.001    23649999.    112.00000
149    54075.001    76387.501    7924994.5    58.000000
150    29137.500    80387.501    58063730.    242.00000
151    29487.501    84112.499    17877491.    427.00000
152    35300.000    82100.000    41840002.    198.00000
153    41362.500    77350.002    12722504.    64.000000
154    41662.500    80312.500    29763764.    160.00000
155    49625.001    78562.502    20248740.    75.000000
156    49950.001    81837.500    37608774.    186.00000
157    59712.502    79375.000    34756268.    294.00000
158    59875.001    82125.000    18222486     138.00000
159    67837.500    85212.500    27336223.    108.00000
160    73637.499    82075.001    13227500.    250.00000
161    75400.000    84075.001    12872489.    249.00000
162    40237.500    86000.000    67134975.    331.00000
163    40687.500    86700.002    51730019.    360.00000
164    56450.000    87137.499    35576254.    197.00000
165    57137.501    83499.998    12788757     126.00000
166    61375.000    87174.999    24764999.    157.00000
167    64075.000    85400.002    4159999.7    32.000000
168    66012.500    89562.500    30193757     232.00000
169    69662.500    90250.000    903753.70    383.00000
170    71750.000    86950.001    18245015.    147.00000
171    74987.501    89775.002    45349987     377.00000
172    29562.500    86775.000    4672504.2    6131.0000
173    32412.500    85700.000    9044998.6    177.00000
174    30037.500    88200.001    884997.41    142.00000
175    33125.000    88525.002    5445003.3    63.000000
176    34687.500    87575.001    2039997.4    107.00000
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177    30775.000    87762.501    4107502.2    66.000000
178    31707.499    89200.001    2567495.1    32.000000
179    44525.000    90137.501    3910752.2    23.000000
180    48312.500    93212.502    42491260.    315.00000
181    49362.501    92262.501    2812498.1    607.00000
182    57262.500    93000.000    59617544.    514.00000
183    65762.500    93650.002    17743739.    395.00000
184    31324.999    94250.000    8589994.8    2200.0000
185    31625.000    92600.000    4250005.1    630.00000
186    33937.500    91574.999    12394993     199.00000
187    34125.000    93975.000    3375005.7    67.000000
188    35937.500    95062.500    3102493.3    24.000000
189    40187.500    92062.500    35154973     222.00000
190    42812.500    96100.000    41667518     241.00000
191    56475.000    98437.502    58593736.    534.00000
192    63937.501    96112.499    4530005.2    43.000000
193    66100.000    97475.000    8762494.1    198.00000
194    68700.001    97350.002    23559982     208.00000
195    72650.000    98087.502    55076241     243.00000
196    63175.000    99262.501    10906258     353.00000
197    64949.999    99550.001    844999.58    352.00000
198    67587.502    102937.50    389999.94    38.000000
199    68975.000    103350.00    9449989.3    111.00000
200    74037.500    105162.50    20002497.    94.000000
201    62487.500    102162.50    2911245.6    117.00000
202    65674.999    101675.00    9015006.7    5965.0000
203    64375.000    103100.00    5369985.2    5170.0000
204    66587.498    105862.50    4199995.1    4374.0000
205    67862.499    105975.00    5062515.0    4374.0000
206    70100.000    106812.50    14320012.    400.00000
207    73137.501    109612.50    5690004.0    108.00000
208    61887.500    104050.00    2148748.8    100.00000
209    63062.500    104300.00    4168758.5    574.00000
210    63425.000    107475.00    8974995.2    500.00000
211    63312.500    110975.00    2102501.1    100.00000
212    64600.000    111150.00    6405006.3    841.00000
213    54962.500    102662.50    34314985.    281.00000
214    42712.501    107500.00    8345009.1    85.000000
215    40474.999    106750.00    14190005.    170.00000
216    38375.000    110950.00    2299996.4    58.000000
217    39462.500    112500.00    4362497.3    106.00000
218    39549.999    111025.00    697500.90    57.000000
219    39275.000    109837.50    1092502.0    37.000000
220    36175.000    98762.499    38818762.    589.00000
221    41787.500    98799.999    19445019     290.00000
222    47450.000    100312.50    22033765     75.000000
223    40412.499    110087.50    3215001.0    314.00000
224    40425.000    102587.50    11724992     219.00000
225    44662.499    101725.00    8532475.3    113.00000
226    43662.500    103612.50    9202506.4    189.00000
227    52924.999    105850.00    19255009     187.00000
228    53450.001    107162.50    3642493.9    418.00000
229    57762.500    108187.50    36494997     295.00000
230    49562.500    109550.00    4239992.3    393.00000
231    46162.500    104950.00    16721247.    123.00000
232    46875.000    109812.50    45597479.    369.00000
233    42475.000    113050.00    17385002.    254.00000
234    52375.000    109150.00    17549976.    130.00000
235    54375.001    113137.50    40143755.    325.00000
236    61225.001    112450.00    38637512     295.00000
237    65212.502    115525.00    14344983.    245.00000
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238    37450.001    121075.00    20650005     277.00000
239    45537.501    119407.50    75347509.    200.00000
240    47407.500    117000.00    25002491.    165.00000
241    50750.001    116007.50    13600004.    133.00000
242    55825.001    117350.00    25775015     130.00000
243    62500.000    110962.50    13174994     81.000000
244    46837.501    121675.00    4006251.6    66.000000
245    47462.501    123737.50    12073756     99.000000
246    48987.500    121707.50    4514996.4    2074.0000
247    54500.000    123000.00    70037700     405.00000
248    37174.999    128737.50    5548757.2    94.000000
249    40762.500    130575.00    95041293     306.00000
250    47075.000    129437.50    6127496.4    45.000000
251    35400.000    132662.50    10158723     64.000000
252    70750.000    51875.000    40625000.    242.00000
253    64562.500    50812.500    35437500.    315.00000
254    57375.000    50875.000    20250000.    189.00000
255    49375.000    49062.500    22573750     330.00000
256    7812.5000    11312.500    13875000.    660.00000
```

```
               CUMMULATIVE CONCENTRATIONS FOR CASE NO      1

 LOC       CONC          LOC       CONC          LOC       CONC          LOC       CONC          LOC       CONC
 NO                      NO                      NO                      NO                      NO

   1  0.000000E+00         2  0.000000E+00         3  0.000000E+00         4  0.000000E+00         5  0.000000E+00
   6  0.000000E+00         7  0.000000E+00         8  0.000000E+00         9  0.000000E+00        10  0.000000E+00
  11  0.000000E+00        12  0.000000E+00        13  0.000000E+00        14  0.000000E+00        15  0.000000E+00
  16  0.000000E+00        17  0.000000E+00        18  0.000000E+00        19  0.000000E+00        20  0.000000E+00
  21  0.000000E+00        22  0.000000E+00        23  0.000000E+00        24  0.000000E+00        25  0.000000E+00
  26  0.000000E+00        27  0.000000E+00        28  0.000000E+00        29  0.000000E+00        30  0.000000E+00
  31  0.000000E+00        32  0.000000E+00        33  0.000000E+00        34  0.000000E+00        35  0.000000E+00
  36  0.000000E+00        37  0.000000E+00        38  0.000000E+00        39  0.000000E+00        40  0.000000E+00
  41  0.000000E+00        42  0.000000E+00        43  0.000000E+00        44  0.000000E+00        45  0.000000E+00
  46  0.000000E+00        47  0.000000E+00        48  0.000000E+00        49  0.000000E+00        50  0.000000E+00
  51  0.000000E+00        52  0.000000E+00        53  0.000000E+00        54  0.000000E+00        55  0.000000E+00
  56  0.000000E+00        57  0.000000E+00        58  0.000000E+00        59  0.000000E+00        60  0.000000E+00
  61  0.000000E+00        62  0.000000E+00        63  0.000000E+00        64  0.000000E+00        65  0.000000E+00
  66  0.000000E+00        67  0.000000E+00        68  0.000000E+00        69  0.000000E+00        70  0.000000E+00
  71  0.000000E+00        72  0.000000E+00        73  0.000000E+00        74  0.000000E+00        75  0.000000E+00
  76  0.000000E+00        77  0.000000E+00        78  0.000000E+00        79  0.000000E+00        80  0.000000E+00
  81  0.000000E+00        82  0.000000E+00        83  0.000000E+00        84  0.000000E+00        85  0.000000E+00
  86  0.000000E+00        87  0.000000E+00        88  0.000000E+00        89  0.000000E+00        90  0.000000E+00
  91  0.000000E+00        92  0.000000E+00        93  0.000000E+00        94  0.000000E+00        95  0.000000E+00
  96  0.000000E+00        97  0.000000E+00        98  0.000000E+00        99  0.000000E+00       100  0.000000E+00
 101  0.000000E+00       102  0.424691E-27       103  0.205159E-18       104  0.000000E+00       105  0.168445E-32
 106  0.118577E-25       107  0.561424E-19       108  0.457254E-17       109  0.182309E-23       110  0.579694E-23
 111  0.497849E-13       112  0.221246E-08       113  0.143020E-13       114  0.591236E-10       115  0.000000E+00
 116  0.000000E+00       117  0.000000E+00       118  0.000000E+00       119  0.000000E+00       120  0.241734E-32
 121  0.492677E-05       122  0.483331           123  0.397039E-06       124  0.436575E-02       125  0.398472E-05
 126  0.603809E-04       127  0.171286E-01       128   1.63651           129   11.8043           130   19.3907
 131  0.000000E+00       132  0.750989           133  0.152867           134  0.242104E-18       135   48.1071
 136  0.606831E-03       137  0.704637           138   22.1380           139   32.5213           140   16.4369
 141  0.233301           142  0.750870           143  0.840317E-01       144  0.116023E-10       145   40.2465
 146   50.7702           147   26.7874           148   6.41022           149   2.17297           150  0.586023E-19
 151  0.000000E+00       152  0.748133E-18       153  0.295137E-01       154  0.403660E-07       155  0.607979E-02
 156  0.108556E-07       157  0.610911E-02       158  0.813622E-06       159  0.148825E-09       160  0.743479E-04
 161  0.267549E-06       162  0.684496E-29       163  0.711542E-23       164  0.334569E-18       165  0.507350E-09
 166  0.704780E-16       167  0.667115E-11       168  0.755328E-20       169  0.637212E-20       170  0.726552E-12
 171  0.981014E-17       172  0.000000E+00       173  0.000000E+00       174  0.000000E+00       175  0.000000E+00
 176  0.000000E+00       177  0.000000E+00       178  0.000000E+00       179  0.000000E+00       180  0.000000E+00
 181  0.000000E+00       182  0.000000E+00       183  0.532609E-32       184  0.000000E+00       185  0.000000E+00
 186  0.000000E+00       187  0.000000E+00       188  0.000000E+00       189  0.000000E+00       190  0.000000E+00
 191  0.000000E+00       192  0.000000E+00       193  0.000000E+00       194  0.000000E+00       195  0.000000E+00
 196  0.000000E+00       197  0.000000E+00       198  0.000000E+00       199  0.000000E+00       200  0.000000E+00
 201  0.000000E+00       202  0.000000E+00       203  0.000000E+00       204  0.000000E+00       205  0.000000E+00
 206  0.000000E+00       207  0.000000E+00       208  0.000000E+00       209  0.000000E+00       210  0.000000E+00
 211  0.000000E+00       212  0.000000E+00       213  0.000000E+00       214  0.000000E+00       215  0.000000E+00
 216  0.000000E+00       217  0.000000E+00       218  0.000000E+00       219  0.000000E+00       220  0.000000E+00
 221  0.000000E+00       222  0.000000E+00       223  0.000000E+00       224  0.000000E+00       225  0.000000E+00
 226  0.000000E+00       227  0.000000E+00       228  0.000000E+00       229  0.000000E+00       230  0.000000E+00
 231  0.000000E+00       232  0.000000E+00       233  0.000000E+00       234  0.000000E+00       235  0.000000E+00
 236  0.000000E+00       237  0.000000E+00       238  0.000000E+00       239  0.000000E+00       240  0.000000E+00
 241  0.000000E+00       242  0.000000E+00       243  0.000000E+00       244  0.000000E+00       245  0.000000E+00
 246  0.000000E+00       247  0.000000E+00       248  0.000000E+00       249  0.000000E+00       250  0.000000E+00
 251  0.000000E+00       252  0.516124E-30       253  0.000000E+00       254  0.000000E+00       255  0.000000E+00
```

```
256   0.000000E+00    257   0.000000E+00    258   0.000000E+00    259   0.000000E+00    260   0.000000E+00
```

```
--- DEBUGGING DUMP OF PK'S ---     FOR CASE  1

NODE #          PERCENTILES OF AFFECTED  ( VALUES OF K )

                0.1000E-01 0.5000     0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00
I,PK(K) :    1  0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00
I,PK(K) :    2  0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00
I,PK(K) :    3  0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00
I,PK(K) :    4  0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00
I,PK(K) :    5  0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00
I,PK(K) :    6  0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00
I,PK(K) :    7  0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00
I,PK(K) :    8  0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00
I,PK(K) :    9  0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00
I,PK(K) :   10  0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00
I,PK(K) :   11  0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00
I,PK(K) :   12  0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00
I,PK(K) :   13  0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00
I,PK(K) :   14  0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00
I,PK(K) :   15  0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00
I,PK(K) :   16  0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00
I,PK(K) :   17  0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00
I,PK(K) :   18  0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00
I,PK(K) :   19  0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00
I,PK(K) :   20  0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00
I,PK(K) :   21  0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00
I,PK(K) :   22  0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00
I,PK(K) :   23  0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00
I,PK(K) :   24  0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00
I,PK(K) :   25  0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00
I,PK(K) :   26  0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00
I,PK(K) :   27  0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00
I,PK(K) :   28  0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00
I,PK(K) :   29  0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00
I,PK(K) :   30  0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00
I,PK(K) :   31  0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00
I,PK(K) :   32  0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00
I,PK(K) :   33  0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00
I,PK(K) :   34  0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00
I,PK(K) :   35  0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00
I,PK(K) :   36  0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00
I,PK(K) :   37  0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00
I,PK(K) :   38  0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00
I,PK(K) :   39  0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00
I,PK(K) :   40  0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00
I,PK(K) :   41  0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00
I,PK(K) :   42  0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00
I,PK(K) :   43  0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00
I,PK(K) :   44  0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00
I,PK(K) :   45  0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00
I,PK(K) :   46  0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00
I,PK(K) :   47  0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00
I,PK(K) :   48  0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00
I,PK(K) :   49  0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00
I,PK(K) :   50  0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00
I,PK(K) :   51  0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00
```

```
I,PK(K) :  52  0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00
I,PK(K) :  53  0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00
I,PK(K) :  54  0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00
I,PK(K) :  55  0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00
I,PK(K) :  56  0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00
I,PK(K) :  57  0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00
I,PK(K) :  58  0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00
I,PK(K) :  59  0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00
I,PK(K) :  60  0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00
I,PK(K) :  61  0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00
I,PK(K) :  62  0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00
I,PK(K) :  63  0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00
I,PK(K) :  64  0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00
I,PK(K) :  65  0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00
I,PK(K) :  66  0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00
I,PK(K) :  67  0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00
I,PK(K) :  68  0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00
I,PK(K) :  69  0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00
I,PK(K) :  70  0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00
I,PK(K) :  71  0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00
I,PK(K) :  72  0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00
I,PK(K) :  73  0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00
I,PK(K) :  74  0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00
I,PK(K) :  75  0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00
I,PK(K) :  76  0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00
I,PK(K) :  77  0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00
I,PK(K) :  78  0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00
I,PK(K) :  79  0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00
I,PK(K) :  80  0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00
I,PK(K) :  81  0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00
I,PK(K) :  82  0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00
I,PK(K) :  83  0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00
I,PK(K) :  84  0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00
I,PK(K) :  85  0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00
I,PK(K) :  86  0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00
I,PK(K) :  87  0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00
I,PK(K) :  88  0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00
I,PK(K) :  89  0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00
I,PK(K) :  90  0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00
I,PK(K) :  91  0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00
I,PK(K) :  92  0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00
I,PK(K) :  93  0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00
I,PK(K) :  94  0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00
I,PK(K) :  95  0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00
I,PK(K) :  96  0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00
I,PK(K) :  97  0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00
I,PK(K) :  98  0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00
I,PK(K) :  99  0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00
I,PK(K) : 100  0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00
I,PK(K) : 101  0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00
I,PK(K) : 102  0.0000E+00 0.0000E+00  1.000     0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00
I,PK(K) : 103  0.0000E+00 0.0000E+00  1.000     0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00
I,PK(K) : 104  0.0000E+00 0.0000E+00  1.000     0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00
I,PK(K) : 105  0.0000E+00 0.0000E+00  1.000     0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00
I,PK(K) : 106  0.0000E+00 0.0000E+00  1.000     0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00
I,PK(K) : 107  0.0000E+00 0.0000E+00  1.000     0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00
I,PK(K) : 108  0.0000E+00 0.0000E+00  1.000     0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00
I,PK(K) : 109  0.0000E+00 0.0000E+00  1.000     0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00
I,PK(K) : 110  0.0000E+00 0.0000E+00  1.000     0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00
I,PK(K) : 111  0.0000E+00 0.0000E+00  1.000     0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00
I,PK(K) : 112  0.0000E+00 0.0000E+00  1.000     0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00
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I,PK(K) :  113   0.0000E+00 0.0000E+00   1.000      0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00
I,PK(K) :  114   0.0000E+00 0.0000E+00   1.000      0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00
I,PK(K) :  115   0.0000E+00 0.0000E+00   1.000      0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00
I,PK(K) :  116   0.0000E+00 0.0000E+00   1.000      0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00
I,PK(K) :  117   0.0000E+00 0.0000E+00   1.000      0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00
I,PK(K) :  118   0.0000E+00 0.0000E+00   1.000      0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00
I,PK(K) :  119   0.0000E+00 0.0000E+00   1.000      0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00
I,PK(K) :  120   0.0000E+00 0.0000E+00   1.000      0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00
I,PK(K) :  121   0.0000E+00 0.0000E+00   1.000      0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00
I,PK(K) :  122   0.0000E+00 0.0000E+00   1.000      0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00
I,PK(K) :  123   0.0000E+00 0.0000E+00   1.000      0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00
I,PK(K) :  124   0.0000E+00 0.0000E+00   1.000      0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00
I,PK(K) :  125   0.0000E+00 0.0000E+00   1.000      0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00
I,PK(K) :  126   0.0000E+00 0.0000E+00   1.000      0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00
I,PK(K) :  127   0.0000E+00 0.0000E+00   1.000      0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00
I,PK(K) :  128   0.0000E+00 0.0000E+00   1.000      0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00
I,PK(K) :  129   0.0000E+00 0.0000E+00   1.000      0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00
I,PK(K) :  130   0.0000E+00 0.0000E+00   1.000      0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00
I,PK(K) :  131   0.0000E+00 0.0000E+00   1.000      0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00
I,PK(K) :  132   0.0000E+00 0.0000E+00   1.000      0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00
I,PK(K) :  133   0.0000E+00 0.0000E+00   1.000      0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00
I,PK(K) :  134   0.0000E+00 0.0000E+00   1.000      0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00
I,PK(K) :  135   0.1354E-06 0.0000E+00   1.000      0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00
I,PK(K) :  136   0.0000E+00 0.0000E+00   1.000      0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00
I,PK(K) :  137   0.0000E+00 0.0000E+00   1.000      0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00
I,PK(K) :  138   0.1388E-16 0.0000E+00   1.000      0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00
I,PK(K) :  139   0.9033E-11 0.0000E+00   1.000      0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00
I,PK(K) :  140   0.0000E+00 0.0000E+00   1.000      0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00
I,PK(K) :  141   0.0000E+00 0.0000E+00   1.000      0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00
I,PK(K) :  142   0.0000E+00 0.0000E+00   1.000      0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00
I,PK(K) :  143   0.0000E+00 0.0000E+00   1.000      0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00
I,PK(K) :  144   0.0000E+00 0.0000E+00   1.000      0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00
I,PK(K) :  145   0.2738E-08 0.0000E+00   1.000      0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00
I,PK(K) :  146   0.3822E-06 0.0000E+00   1.000      0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00
I,PK(K) :  147   0.1693E-13 0.0000E+00   1.000      0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00
I,PK(K) :  148   0.0000E+00 0.0000E+00   1.000      0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00
I,PK(K) :  149   0.0000E+00 0.0000E+00   1.000      0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00
I,PK(K) :  150   0.0000E+00 0.0000E+00   1.000      0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00
I,PK(K) :  151   0.0000E+00 0.0000E+00   1.000      0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00
I,PK(K) :  152   0.0000E+00 0.0000E+00   1.000      0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00
I,PK(K) :  153   0.0000E+00 0.0000E+00   1.000      0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00
I,PK(K) :  154   0.0000E+00 0.0000E+00   1.000      0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00
I,PK(K) :  155   0.0000E+00 0.0000E+00   1.000      0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00
I,PK(K) :  156   0.0000E+00 0.0000E+00   1.000      0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00
I,PK(K) :  157   0.0000E+00 0.0000E+00   1.000      0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00
I,PK(K) :  158   0.0000E+00 0.0000E+00   1.000      0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00
I,PK(K) :  159   0.0000E+00 0.0000E+00   1.000      0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00
I,PK(K) :  160   0.0000E+00 0.0000E+00   1.000      0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00
I,PK(K) :  161   0.0000E+00 0.0000E+00   1.000      0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00
I,PK(K) :  162   0.0000E+00 0.0000E+00   1.000      0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00
I,PK(K) :  163   0.0000E+00 0.0000E+00   1.000      0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00
I,PK(K) :  164   0.0000E+00 0.0000E+00   1.000      0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00
I,PK(K) :  165   0.0000E+00 0.0000E+00   1.000      0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00
I,PK(K) :  166   0.0000E+00 0.0000E+00   1.000      0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00
I,PK(K) :  167   0.0000E+00 0.0000E+00   1.000      0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00
I,PK(K) :  168   0.0000E+00 0.0000E+00   1.000      0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00
I,PK(K) :  169   0.0000E+00 0.0000E+00   1.000      0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00
I,PK(K) :  170   0.0000E+00 0.0000E+00   1.000      0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00
I,PK(K) :  171   0.0000E+00 0.0000E+00   1.000      0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00
I,PK(K) :  172   0.0000E+00 0.0000E+00   1.000      0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00
I,PK(K) :  173   0.0000E+00 0.0000E+00   1.000      0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00
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I,PK(K) :  174   0.0000E+00 0.0000E+00  1.000    0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00
I,PK(K) :  175   0.0000E+00 0.0000E+00  1.000    0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00
I,PK(K) :  176   0.0000E+00 0.0000E+00  1.000    0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00
I,PK(K) :  177   0.0000E+00 0.0000E+00  1.000    0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00
I,PK(K) :  178   0.0000E+00 0.0000E+00  1.000    0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00
I,PK(K) :  179   0.0000E+00 0.0000E+00  1.000    0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00
I,PK(K) :  180   0.0000E+00 0.0000E+00  1.000    0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00
I,PK(K) :  181   0.0000E+00 0.0000E+00  1.000    0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00
I,PK(K) :  182   0.0000E+00 0.0000E+00  1.000    0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00
I,PK(K) :  183   0.0000E+00 0.0000E+00  1.000    0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00
I,PK(K) :  184   0.0000E+00 0.0000E+00  1.000    0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00
I,PK(K) :  185   0.0000E+00 0.0000E+00  1.000    0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00
I,PK(K) :  186   0.0000E+00 0.0000E+00  1.000    0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00
I,PK(K) :  187   0.0000E+00 0.0000E+00  1.000    0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00
I,PK(K) :  188   0.0000E+00 0.0000E+00  1.000    0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00
I,PK(K) :  189   0.0000E+00 0.0000E+00  1.000    0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00
I,PK(K) :  190   0.0000E+00 0.0000E+00  1.000    0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00
I,PK(K) :  191   0.0000E+00 0.0000E+00  1.000    0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00
I,PK(K) :  192   0.0000E+00 0.0000E+00  1.000    0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00
I,PK(K) :  193   0.0000E+00 0.0000E+00  1.000    0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00
I,PK(K) :  194   0.0000E+00 0.0000E+00  1.000    0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00
I,PK(K) :  195   0.0000E+00 0.0000E+00  1.000    0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00
I,PK(K) :  196   0.0000E+00 0.0000E+00  1.000    0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00
I,PK(K) :  197   0.0000E+00 0.0000E+00  1.000    0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00
I,PK(K) :  198   0.0000E+00 0.0000E+00  1.000    0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00
I,PK(K) :  199   0.0000E+00 0.0000E+00  1.000    0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00
I,PK(K) :  200   0.0000E+00 0.0000E+00  1.000    0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00
I,PK(K) :  201   0.0000E+00 0.0000E+00  1.000    0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00
I,PK(K) :  202   0.0000E+00 0.0000E+00  1.000    0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00
I,PK(K) :  203   0.0000E+00 0.0000E+00  1.000    0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00
I,PK(K) :  204   0.0000E+00 0.0000E+00  1.000    0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00
I,PK(K) :  205   0.0000E+00 0.0000E+00  1.000    0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00
I,PK(K) :  206   0.0000E+00 0.0000E+00  1.000    0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00
I,PK(K) :  207   0.0000E+00 0.0000E+00  1.000    0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00
I,PK(K) :  208   0.0000E+00 0.0000E+00  1.000    0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00
I,PK(K) :  209   0.0000E+00 0.0000E+00  1.000    0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00
I,PK(K) :  210   0.0000E+00 0.0000E+00  1.000    0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00
I,PK(K) :  211   0.0000E+00 0.0000E+00  1.000    0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00
I,PK(K) :  212   0.0000E+00 0.0000E+00  1.000    0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00
I,PK(K) :  213   0.0000E+00 0.0000E+00  1.000    0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00
I,PK(K) :  214   0.0000E+00 0.0000E+00  1.000    0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00
I,PK(K) :  215   0.0000E+00 0.0000E+00  1.000    0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00
I,PK(K) :  216   0.0000E+00 0.0000E+00  1.000    0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00
I,PK(K) :  217   0.0000E+00 0.0000E+00  1.000    0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00
I,PK(K) :  218   0.0000E+00 0.0000E+00  1.000    0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00
I,PK(K) :  219   0.0000E+00 0.0000E+00  1.000    0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00
I,PK(K) :  220   0.0000E+00 0.0000E+00  1.000    0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00
I,PK(K) :  221   0.0000E+00 0.0000E+00  1.000    0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00
I,PK(K) :  222   0.0000E+00 0.0000E+00  1.000    0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00
I,PK(K) :  223   0.0000E+00 0.0000E+00  1.000    0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00
I,PK(K) :  224   0.0000E+00 0.0000E+00  1.000    0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00
I,PK(K) :  225   0.0000E+00 0.0000E+00  1.000    0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00
I,PK(K) :  226   0.0000E+00 0.0000E+00  1.000    0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00
I,PK(K) :  227   0.0000E+00 0.0000E+00  1.000    0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00
I,PK(K) :  228   0.0000E+00 0.0000E+00  1.000    0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00
I,PK(K) :  229   0.0000E+00 0.0000E+00  1.000    0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00
I,PK(K) :  230   0.0000E+00 0.0000E+00  1.000    0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00
I,PK(K) :  231   0.0000E+00 0.0000E+00  1.000    0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00
I,PK(K) :  232   0.0000E+00 0.0000E+00  1.000    0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00
I,PK(K) :  233   0.0000E+00 0.0000E+00  1.000    0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00
I,PK(K) :  234   0.0000E+00 0.0000E+00  1.000    0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00
```

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I,PK(K) :  235   0.0000E+00 0.0000E+00  1.000     0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00
I,PK(K) :  236   0.0000E+00 0.0000E+00  1.000     0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00
I,PK(K) :  237   0.0000E+00 0.0000E+00  1.000     0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00
I,PK(K) :  238   0.0000E+00 0.0000E+00  1.000     0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00
I,PK(K) :  239   0.0000E+00 0.0000E+00  1.000     0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00
I,PK(K) :  240   0.0000E+00 0.0000E+00  1.000     0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00
I,PK(K) :  241   0.0000E+00 0.0000E+00  1.000     0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00
I,PK(K) :  242   0.0000E+00 0.0000E+00  1.000     0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00
I,PK(K) :  243   0.0000E+00 0.0000E+00  1.000     0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00
I,PK(K) :  244   0.0000E+00 0.0000E+00  1.000     0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00
I,PK(K) :  245   0.0000E+00 0.0000E+00  1.000     0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00
I,PK(K) :  246   0.0000E+00 0.0000E+00  1.000     0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00
I,PK(K) :  247   0.0000E+00 0.0000E+00  1.000     0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00
I,PK(K) :  248   0.0000E+00 0.0000E+00  1.000     0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00
I,PK(K) :  249   0.0000E+00 0.0000E+00  1.000     0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00
I,PK(K) :  250   0.0000E+00 0.0000E+00  1.000     0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00
I,PK(K) :  251   0.0000E+00 0.0000E+00  1.000     0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00
I,PK(K) :  252   0.0000E+00 0.0000E+00  1.000     0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00
I,PK(K) :  253   0.0000E+00 0.0000E+00  1.000     0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00
I,PK(K) :  254   0.0000E+00 0.0000E+00  1.000     0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00
I,PK(K) :  255   0.0000E+00 0.0000E+00  1.000     0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00
I,PK(K) :  256   0.0000E+00 0.0000E+00  1.000     0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00
```

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        NUMBER OF FATALITIES VERSUS PROBABILITY FOR CASE     1
NODE #               PROBABILITY LEVEL

        0.1000E-06 0.1000E-04 0.1000E-02 0.1000


   1    0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00
   2    0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00
   3    0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00
   4    0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00
   5    0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00
   6    0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00
   7    0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00
   8    0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00
   9    0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00
  10    0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00
  11    0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00
  12    0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00
  13    0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00
  14    0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00
  15    0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00
  16    0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00
  17    0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00
  18    0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00
  19    0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00
  20    0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00
  21    0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00
  22    0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00
  23    0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00
  24    0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00
  25    0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00
  26    0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00
  27    0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00
  28    0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00
  29    0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00
  30    0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00
  31    0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00
  32    0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00
  33    0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00
  34    0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00
  35    0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00
  36    0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00
  37    0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00
  38    0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00
  39    0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00
  40    0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00
  41    0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00
  42    0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00
  43    0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00
  44    0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00
  45    0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00
  46    0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00
  47    0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00
  48    0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00
  49    0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00
  50    0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00
  51    0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00
```

```
 52   0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00
 53   0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00
 54   0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00
 55   0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00
 56   0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00
 57   0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00
 58   0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00
 59   0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00
 60   0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00
 61   0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00
 62   0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00
 63   0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00
 64   0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00
 65   0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00
 66   0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00
 67   0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00
 68   0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00
 69   0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00
 70   0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00
 71   0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00
 72   0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00
 73   0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00
 74   0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00
 75   0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00
 76   0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00
 77   0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00
 78   0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00
 79   0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00
 80   0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00
 81   0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00
 82   0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00
 83   0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00
 84   0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00
 85   0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00
 86   0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00
 87   0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00
 88   0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00
 89   0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00
 90   0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00
 91   0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00
 92   0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00
 93   0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00
 94   0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00
 95   0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00
 96   0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00
 97   0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00
 98   0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00
 99   0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00
100   0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00
101   0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00
102     5.070      5.070      5.065      4.563
103     2.960      2.960      2.957      2.664
104   0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00
105     5.790      5.790      5.784      5.211
106     1.230      1.230      1.229      1.107
107    0.8300     0.8300     0.8292     0.7470
108     3.700      3.700      3.696      3.330
109     63.16      63.16      63.10      56.84
110     7.790      7.790      7.782      7.011
111     4.270      4.270      4.266      3.843
112    0.4000     0.4000     0.3996     0.3600
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113      5.080      5.080      5.074      5.272
114     24.50      24.50      24.56      22.12
115   0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00
116   0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00
117   0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00
118   0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00
119   0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00
120      4.650      4.650      4.645      4.185
121      3.460      3.460      3.457      3.114
122      1.160      1.160      1.159      1.044
123      4.210      4.210      4.206      3.789
124      3.800      3.800      3.796      3.420
125      2.130      2.130      2.128      1.917
126      3.570      3.570      3.566      3.213
127     0.6800     0.6800     0.6793     0.6120
128      4.020      4.020      4.016      3.618
129      2.010      2.010      2.008      1.809
130      1.380      1.380      1.379      1.242
131   0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00
132     0.2500     0.2500     0.2497     0.2250
133      5.680      5.680      5.674      5.112
134      4.690      4.690      4.685      4.221
135      5.388     0.3900     0.3896     0.3510
136      2.950      2.950      2.947      2.655
137     0.4700     0.4900     0.4895     0.4410
138      3.490      3.490      3.487      3.141
139     18.40      18.40      18.38      16.56
140      3.880      3.880      3.876      3.492
141      5.180      5.180      5.175      4.662
142      1.450      1.450      1.449      1.305
143     0.7900     0.7900     0.7892     0.7110
144      3.520      3.520      3.516      3.168
145      3.200      3.200      3.197      2.880
146    386.3       10.39      10.38       9.351
147      1.600      1.600      1.598      1.440
148      1.120      1.120      1.119      1.008
149     0.5800     0.5800     0.5794     0.5220
150      2.420      2.420      2.418      2.178
151   0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00
152      1.980      1.980      1.978      1.782
153     0.6400     0.6400     0.6394     0.5760
154      1.600      1.600      1.598      1.440
155     0.7500     0.7500     0.7492     0.6750
156      1.860      1.860      1.858      1.674
157      2.940      2.940      2.937      2.646
158      1.380      1.380      1.379      1.242
159      1.080      1.080      1.079     0.9720
160      2.500      2.500      2.497      2.250
161      2.490      2.490      2.488      2.241
162      3.310      3.310      3.307      2.979
163      3.600      3.600      3.596      3.240
164      1.970      1.970      1.968      1.773
165      1.260      1.260      1.259      1.134
166      1.570      1.570      1.568      1.413
167     0.3200     0.3200     0.3197     0.2880
168      2.320      2.320      2.318      2.088
169      3.830      3.830      3.826      3.447
170      1.470      1.470      1.469      1.323
171      3.770      3.770      3.766      3.393
172   0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00
173   0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00
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174   0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00
175   0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00
176   0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00
177   0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00
178   0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00
179   0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00
180   0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00
181   0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00
182   0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00
183     3.950      3.950      3.946      3.555
184   0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00
185   0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00
186   0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00
187   0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00
188   0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00
189   0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00
190   0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00
191   0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00
192   0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00
193   0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00
194   0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00
195   0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00
196   0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00
197   0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00
198   0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00
199   0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00
200   0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00
201   0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00
202   0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00
203   0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00
204   0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00
205   0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00
206   0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00
207   0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00
208   0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00
209   0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00
210   0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00
211   0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00
212   0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00
213   0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00
214   0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00
215   0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00
216   0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00
217   0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00
218   0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00
219   0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00
220   0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00
221   0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00
222   0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00
223   0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00
224   0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00
225   0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00
226   0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00
227   0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00
228   0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00
229   0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00
230   0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00
231   0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00
232   0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00
233   0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00
234   0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00
```

```
235      0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00
236      0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00
237      0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00
238      0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00
239      0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00
240      0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00
241      0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00
242      0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00
243      0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00
244      0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00
245      0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00
246      0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00
247      0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00
248      0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00
249      0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00
250      0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00
251      0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00
252       2.420      2.420      2.410      2.170
253      0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00
254      0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00
255      0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00
256      0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00
```

```
SUM OF FATALITIES OVER MAP FOR CASE  1

     PJ(J)          FATALITIES
  0 1000E-06           655 1
  0 1000E-04           274 2
  0 1000E-02           273 9
  0 1000               246 8
```

POOR

QUALITY

ORIGINAL